INTRODUCTORY MANUAL
FOR
SUGAR GROWERS

FRANCIS WATTS

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BY

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PREFACE.

An experience of some years in the West Indies has led me to see the necessity for some simple hand-book for the use of those engaged in the sugar industry—a hand-book containing an outline of the principles of agriculture based on modern scientific discoveries, and also an outline of the principles underlying the manufacture of sugar.

An attempt is made in the following pages to collect together in as simple a manner as possible a series of observations on these points, in the hope that they will serve as a starting-point for young overseers about to begin their training in the sugar-fields and boiling-houses, and also, perhaps, as a means of rendering more easy and accessible to older men the information to be obtained from larger works and from scattered papers and pamphlets.

One difficulty which sugar growers experience is that writers on agriculture have rarely written upon their special subject, but have treated of the methods and productions of temperate climates; hence there has often been a doubt as to the extent to which the writers' remarks could be with

safety applied to a tropical plant and under tropical conditions.

A sugar literature is now springing up, and it is hoped that this little book may be one of a series of hand-books, each dealing in a more exhaustive manner than in the present case with some one branch of the sugar industry. If a number of competent writers could be induced to contribute to this end, such a course would do much to give accuracy and precision in the place of the old "rule of thumb."

FRANCIS WATTS.

GOVERNMENT LABORATORY, ANTIGUA, W. I.,
November, 1892.

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MANUAL FOR SUGAR GROWERS.

CHAPTER I.

Introduction.—Chemical Elements and Symbols.—Cells, Tissues, and Fibro-vascular Bundles.—Structure and Function of Roots, Stems, and Leaves.

IN the study of agriculture an acquaintance with a number of sciences is necessary. Prominent among these are chemistry and botany, some knowledge of chemistry being necessary in order that the changes taking place in soils under tillage and cropping may be understood and the requirements of the crops economically supplied. The sugar grower, being also as a rule a sugar manufacturer, requires to know some chemical facts in order that he may understand the changes to which sugar is liable, and how to promote advantageous ones while preventing those which are harmful. A knowledge of the fundamental principles of plant life and nutrition is quite invaluable to all engaged in agriculture.

One of the most important facts which chemistry has taught us is the indestructibility of matter: nothing is created, nothing is destroyed in the con-

tinuous changes which are observed daily, these changes being simply the result of the re-arrangement of the same matter over and over again in the ever-varying forms existing on the earth.

Another important fact is the knowledge that all the things in the world result from the combination of two or more of some sixty-five simple substances, or, as chemists call them, elements. These elements are each composed of one kind of matter only, "and out of each no two or more essentially differing substances can be obtained."

A list of the elements, with their combining weights, is given in the table on page 138.

Some of these elements are extremely rare substances, while others exist in enormous quantities. The following are those which enter into combination to form all the various parts of plants and plant products:

Hydrogen.	Potassium.	Sodium.
Oxygen.	Calcium.	Manganese.
Carbon.	Magnesium.	Silicon.
Nitrogen.	Iron.	Chlorine.
Sulphur.	Phosphorus.	

From this it follows that if some particular element be wanted—say, for instance, potassium—to supply plant-food in a soil deficient in that element, then something containing potassium must be used to supply the defect, for out of no combination of substances can potassium be created. It must exist in the substance employed, for matter cannot

be created or destroyed, nor can the elements be changed one into the other; potassium is always potassium, nitrogen always nitrogen, and so on, though the substances which can be obtained by combining these elements in various ways are endless in number.

For the sake of convenience it is customary to represent each element by means of a symbol, usually the first letter of its name, and this symbol also indicates a definite quantity of the element, the equivalent or combining weight. Thus the symbol C indicates carbon, but it also stands for twelve parts by weight of carbon. (See equivalent weights in table.) Again, the symbols H and O stand for one part by weight of hydrogen and sixteen of oxygen respectively. Compounds are formed by the union of two or more elements and are represented symbolically by writing the symbols of the constituent elements together, the quantity of any particular element present in a compound being indicated by a small figure placed a little below and to the right of the element in question: thus, water is found by experiment to be composed of the elements oxygen and hydrogen, and also to contain two parts by weight of hydrogen to sixteen parts by weight of oxygen. These facts are represented by the symbol H_2O.*

* For a full explanation of this subject any good elementary text-book should be consulted, this outline being merely given in order that the chemical formulæ, etc., necessarily employed may be to some extent understood by those having no chemical knowledge.

All vegetable structures are built up of minute cells of very various shape. The simplest cell is a chamber whose walls are thin and usually has fluid contents: these cells joined together form a tissue, and aggregates of different tissues form the root, stem, and leaves, the three portions of which plants consist. In order to study these cells the microscope must be employed. A thin slice of the soft part of the sugar-cane, cut lengthwise, presents the appearance shown in Fig. 1, where it will be seen that the greater portion of the stem is composed of cells which are of about the same length as breadth, with thin walls, and having, as seen in section, a honeycomb-like appearance; these are usually spoken of as *cells*—ordinary cells, without any qualifying term. Traversing this cellular tissue will be seen a number of thread-like cells running parallel with each other; a closer inspection, on magnifying these threads to a greater degree, as seen in Fig. 2, shows that the thread-like cells are not all alike. Some are tubes with thin walls, having rings arranged on the inside of the

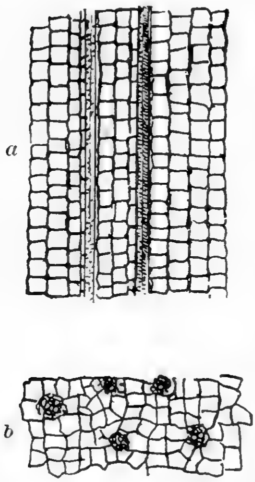

FIG. 1.—Fibro-vascular bundles in sugar-cane; *a*, longitudinal; *b*, transverse section.

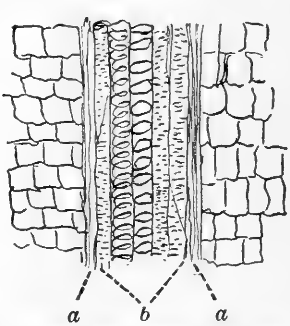

FIG. 2.—Fibro-vascular bundles in sugar-cane; *a*, fibres; *b*, vessels.

tube, in others a fine thread is wound in a spiral throughout the length of the tube, while others present the appearance of being perforated with minute holes. These thin-walled long cells are known as vessels, and are named, according to the markings on their walls, annular or ringed vessels, spiral vessels, dotted vessels, etc. Lying round these vessels just described will be seen a number of long thread-like cells, the walls of which are thicker and display no particular marking; these cells are generally of smaller diameter than the vessels, and the walls are considerably thickened; they are commonly spoken of as fibres or fibrous cells: hence the collection of fibres and vessels which has been described is generally known as a fibro-vascular bundle, and these bundles will be found traversing the cellular tissue in all parts of the plant.

When vegetable tissues are burned one portion disappears in the form of gas or vapour, while a small portion remains behind as ash; the portion which disappears is composed of the elements carbon, hydrogen, oxygen, nitrogen, with some of the sulphur; the ash contains the remaining elements mentioned in the list on page 2; these are combined with oxygen, and are generally spoken of as mineral constituents, or sometimes as ash constituents. These facts are familiar to planters from burning megass.

The walls of the cells already described are composed of carbon, hydrogen, and oxygen arranged in the following proportions, $C_6H_{10}O_5$,* forming a

* Inspection will show that this substance is composed of six equivalents of carbon with five equivalents of water. These com-

substance known as cellulose. In the interior of each living cell is a little mass of jelly-like substance known as protoplasm; this is a substance of the greatest importance, for it is the source of all the vital functions of the plant, which plant may be compared to a large barracks, each cell being a little room, the inhabitant of each room being the living protoplasm. All growth, all production of useful substances, depend on the life and changes taking place in the protoplasm. To support life and to maintain growth, food of course is necessary, so the protoplasmic contents of the cells must be fed. The food consists of mineral matter with nitrogen compounds brought up from the root, together with compounds containing much carbon obtained from the leaves. The functions of the roots and leaves will be shortly explained.

The usual method of propagating the sugar-cane is by planting short lengths of the stem or cane, the upper portion or top being usually selected for this purpose. When placed in moist soil a number of roots make their appearance from the double row of marks arranged just above each joint, and a new stem or cane grows from each bud, or eye.

The Root.—The sugar-cane has no main root, but like all grasses possesses a great number of fine rootlets; these spread to a great distance and to

pounds—in which hydrogen and oxygen exist in the same proportion as in water, namely, two equivalents of hydrogen to one of oxygen—are called carbo-hydrates. Cane-sugar, $C_{12}H_{22}O_{11}$, glucose, $C_6H_{12}O_6$, starch, $C_6H_{10}O_5$, and a vast number of other substances, are carbo-hydrates.

a considerable depth in suitable soil. The results would be of considerable interest and value if planters would make a series of observations on the range of the roots of the sugar-cane. The observations of Mr. Henry Ling Roth are among the best known, and as the result of these it may be stated that in good soil the majority of the rootlets reach a depth of about two feet, a smaller number extending even to four and five feet; the lateral spread is from three to four feet. The author's observations lead to the conclusion that in moderately well-tilled soil the roots grow downward until they reach the layer of soil but little disturbed by cultivation, and then spread laterally; so that the depth to which the roots descend in stiff soil depends on the depth of the tillage. If the extremities of the rootlets be examined they will be found to be very fine and tender and also to adhere closely to the particles of soil with which they come in contact. A closer inspection will show why this is. If examined with a magnifying-glass it will be seen that the fine rootlet, instead of being perfectly smooth, is, on the contrary, clothed with a quantity of exceedingly delicate hair, but only for a short distance near the tip; a short way back the hairs die off and the rootlet becomes smooth. These root-hairs are of interest, for it is by means of these that the plant absorbs moisture from the soil, and with the moisture the mineral plant-food which the soil supplies. If the extremity of the rootlet be examined it will be found to be clothed with a little cap or sheath, the use of which a moment's consideration will render

evident: roots increase in length only at their ends, so that the end always consists of young and deli-

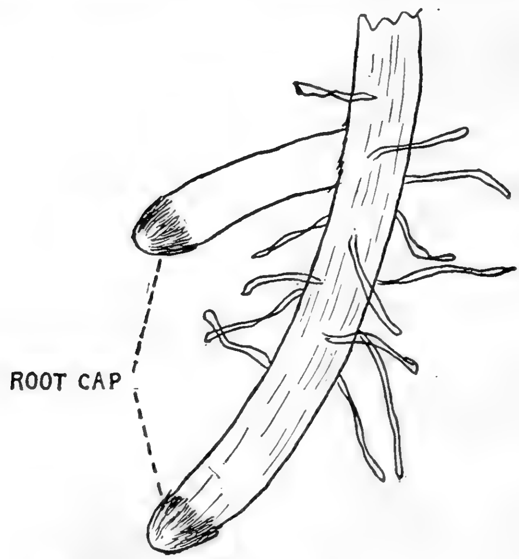

FIG. 3.—Rootlet, with root-hairs and root-cap.

cate cells which must be protected from injury while being thrust through the soil; the root-cap therefore affords protection to the delicate cells lying beneath it. The root at intervals throws out branches which from their earliest appearance are clothed with a root-cap, and root-hairs soon develop near the end. It will easily be seen why it is impossible for roots to lengthen except at their extremities, for the root-branches imbedded in the soil would be torn off if the main root grew in length in the parts between their respective bases.*

*In taking up a rootlet for examination for root-hairs and root-cap, care must be taken in removing the soil, as these organs are very delicate. The examination of rootlets growing under a flat stone is often highly satisfactory.

Internally, the structure of the root may be briefly described as a mass of cellular tissue through the centre of which passes a heart or core composed of fibro-vascular bundles; the outside is covered with a layer of somewhat hardened cells forming a kind of bark.

The function of the root is twofold: it serves to fix the plant in the ground and also to absorb certain food-materials from the soil; it is in doing this that the root-hairs play an important part. Only plant-food in a state of solution can enter the root, and that almost entirely through the root-hairs; the older parts of the roots are almost destitute of absorbing power, and thus the extremities of the roots and rootlets are the only parts by which water with plant-food in solution can enter the plant,—a point to be borne in mind in the application of manures. The actual manner in which the root absorbs food is by the process known as osmose; this may be thus explained: When two fluids are separated from each other by a thin membrane, various substances dissolved in one of the fluids have the power of passing through the membrane and thus appearing in the fluid on the other side, and this transfer of material will go on until the two fluids become of the same strength; this may be experimentally illustrated by placing some strong solution of salt in a bladder, and, after tying it up securely, placing it for a few hours in a basin of water. On examining the water it will be found to be quite salt, the salt having passed through the bladder by the process of osmose. Only those substances which are capable of crystallising can

thus pass through the membrane; they are distinguished as crystalloids. Now crystalline substances like gelatine, albumen, etc., cannot pass through, and are known as colloids. In the root the cells are the bladders, but with the solution of plant-food outside them; this is continually passing into the cells; the solution inside the cells is prevented from becoming of the same strength as that on the outside, owing to the transfer of the plant-food by further osmose into other cells, till it is finally used in the process of growth.

The Leaf.—The leaf of the sugar-cane is about four feet long and two inches wide, tapering to a point; the leaf-stalk is developed into a sheath which closely embraces the stem. In internal structure the leaf is somewhat complicated; the upper and under surfaces are covered with a skin or tissue called the epidermis, which is composed of thin-walled flat cells having colourless contents; between the upper and under epidermis is a mass of tissue the cells of which are filled with green contents; running from end to end of the leaf are veins which are continuations of the fibro-vascular bundles of the stem. It will be seen in the drawing (Fig. 4) that these cells having green-coloured contents are not packed closely together, but that there are air-spaces between them, these air-spaces being very large in some places; it will be noticed, too, that these air-spaces are in connection with the outer air by means of openings through the epidermis. If a little of the epidermis be stripped off and examined with the microscope, these openings may be readily distinguished; the epidermis is

seen to consist of cells of somewhat irregular outline, while the contents are colourless; at intervals

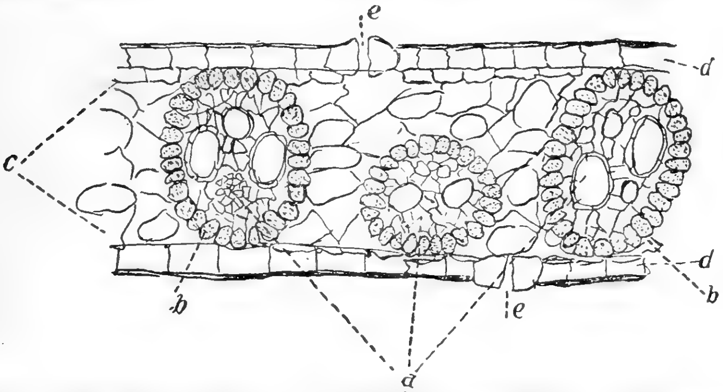

FIG. 4.—Transverse section of sugar-cane leaf (magnified); *a*, fibro-vascular bundles surrounded by (*b*) layer of cells containing chlorophyll; *c*, cells with colourless contents and air-cells; *d*, epidermis; *e*, stomata.

there will be seen pairs of cells having green contents; these are crescent-shaped and lie with their points touching, so that there is a space between their opposing faces; this space is the opening communicating with the interior air-spaces of the leaf; these crescent-shaped cells are known as guard-cells and the whole (guard-cells and aperture) is termed a stoma or mouth; by means of these stomata the interior cells of the leaf are in intimate contact with the atmosphere. The atmosphere, which for the most part is composed of two gases, nitrogen and oxygen, contains also a very small quantity of a gas known as carbonic acid or carbon dioxide, a substance composed of carbon and oxygen and having the composition represented by

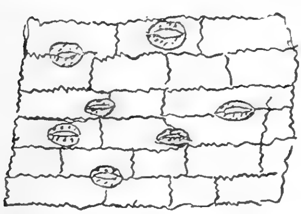

FIG. 5. — Epidermis of leaf with stomata (magnified).

the formula CO_2; this gas is produced whenever any organic substance is burned, thus every fire is a source of it; it is present in the breath of all animals, a human being giving off about seven hundred pints every day, containing nearly eight ounces of carbon. This gas is fatal to animal life, and unless some means for its removal existed the whole atmosphere would become poisonous and animal life would cease. This gas is one of the most important plant-foods, for the cells possessing the green colouring matter above referred to have the power of decomposing it, retaining the carbon and returning the oxygen to the atmosphere. Animal and vegetable life are thus dependent on each other. Two things are necessary for this process of plant-respiration: the green colouring matter (or chlorophyll, as it is called) and sunlight,—the process ceasing in the absence of light. This affords an explanation of the fact that plants become sickly if grown in rooms or dark places where they are not exposed to sufficient light.

It is from this source that all the carbon found in vegetable structures and products is obtained; and what an important part of plant life, and how entirely the production of such substances as sugar depends on it, will be readily recognised if it be remembered that sugar contains nearly half its own weight of carbon.

The first substance produced by the plant from the carbon obtained by respiration is starch; this is composed of carbon, oxygen, and hydrogen, having the formula $C_6H_{10}O_5$; the starch thus formed is quickly converted into other and soluble substances,

and conveyed down the leaf-stalk into the stem, to be used as food in the development of new tissues; or stored up as a reserve food-supply in the form of sugar (in some plants as starch) to support growth when the daily supply of carbon is insufficient to meet some rapid development. An experiment shows the formation of starch in the leaf, the influence of light on its production, and the fact of its removal. The leaf of a plant—such, for instance, as a rose—is placed in spirit for a short time until all the green colouring matter is removed and the leaf left white; the leaf is now washed with water and finally placed in water containing iodine in solution; the effect of the iodine on the starch is to turn it blue, so that the leaf becomes of a blue-black colour from the presence of starch. A small plant is taken and excluded from sunlight for from twelve to twenty-four hours, by being covered with a box, or by other suitable means: if the leaves of this plant be treated in the manner described above, they will not be coloured blue by iodine, showing the absence of starch,—the starch formed during the period of exposure to sunlight being removed from the leaf by vital processes, and used as a food-material in the ordinary course of nutrition and growth.

Another important function of the leaf is transpiration, or the evaporation of the superfluous water of the crude sap in the form of vapour. The quantity of water given off from the leaves of various crops has been made the subject of experiment; the amount transpired is found to be very great,—as much as two

or three thousand gallons per acre per day in some cases. The effect of this transpiration is to concentrate the crude sap, thus promoting the absorption of water by the roots, and also causing free circulation of the sap in the plant. In this way the leaf acts both as a feeding and circulating organ.

The Stem.—Most plants, during their period of growth, assimilate a greater quantity of material than is immediately employed in building up tissues, and this excess of food-material is stored away in some part of the plant adapted for its accumulation. The form in which the reserve is accumulated varies; thus there is the starch in the root of cassava and arrowroot, oil in the seeds of various plants, and in the sugar-cane sugar is stored up in the stem. These reserves are generally drawn upon to meet the demands of rapid growth at the times of flowering and fruiting, and doubtless it is with this object that the sugar-cane still accumulates sugar, though by cultivation the production of seed has been discouraged, while the tendency to secrete sugar has probably been fostered and increased.

Thus we have: 1. The root, supplying mineral and nitrogenous food and water. 2. The leaf, supplying carbonaceous food under the influence of sunlight, and throwing off the surplus water. 3. The stem, acting as a storehouse of reserve food-material, sugar.

The reader is advised to consult a botanical text-book for a more complete account of the structures and functions briefly given in outline here.

CHAPTER II.

Origin of Soil, Clay, Chalk or Marl, Sand.—Fertile Soil.—Conditions Influencing Fertility.—"Condition or Heart."—Function of Vegetable Matter in the Soil.—Moisture.—Mineral Plant-food.—Analysis of Soils.—Nitrogenous Plant food.—Nitrification.—Leguminous Crops and Nitrogen.—Root-nodules.—Retention of Plant-foods by Soils.—Drainage.

IN practical agriculture the first thing to be considered is the soil, for on the nature of the soil will depend the kind of crops which can be grown, and whether the undertaking will prove remunerative.

Soils have their origin in the decomposition of rocks, and will differ in composition and character according to the nature of the rocks from which they are derived. A cursory glance in almost any country will show soils in process of formation; the rocks exposed and supporting a scanty vegetation, the roots of which, penetrating the small fissures, tend to enlarge them, while the whole plant causes soil to accumulate by preventing the rain and wind from removing the finer particles, to which the action of the weather, amongst other things, gives rise. On the death of the plant its decaying remains increase the amount of soil and render the spot capable of supporting a much more vigorous growth of plants; and this combined action of weather and vegetation goes on till often a very considerable

depth of soil is formed. The action of the weather alone might give rise to a clay, the presence of vegetable matter being necessary to render this a true soil.

Rocks are divided into two classes, according to whether they owe their origin to volcanic agency or have been deposited in water; and these facts have an important bearing on the nature of the soil and on the agricultural operations to which it should be subjected. Apart from their geologic origin, soils may be divided into clays, marls, and sands, and this division is of immense service in agriculture.

Clay has its origin in the decomposition of rocks containing felspar, and when pure consists of silicate of alumina; it very rarely occurs in a pure state, being usually mixed with varying amounts of sand, marl, etc. It is characterized by its coherence, plasticity, want of porosity, and slow permeability by water; many of these properties are disadvantageous from an agricultural point of view, and require to be modified by judicious operations of tillage, etc. *Pure* clay also contains no plant-food, but the clays usually existing as soils contain considerable admixture of substances of value. Clays may have their origin in both volcanic and sedimentary rocks.

Chalk,—or, as it is frequently termed, marl,—when pure, is carbonate of lime, but, as existing as soil, it owes its origin to the decomposition of coral, shells, and the like, and thus contains a variety of substances valuable as plant-food, particularly phosphate of lime. Marls, not containing much sand or stony matter, tend to set into a stiff, clay-like soil, which may be termed coral clay or marly clay; and

this, though often rich in plant-food, requires skilled management to keep it in good condition and enable it to produce large crops.

Sand is the term applied to those soils possessing but little coherence and very permeable by water; the mineral of which it is composed is frequently silica or various silicious minerals. When the fragments or individual particles are large, the term gravel is employed. Pure sand, like pure clay and pure chalk, is incapable of supporting vegetable life, so that neither of these substances in a pure state will constitute what is generally understood by the term soil.

A fertile soil consists of an admixture in varying proportions of the three substances above named, together with a suitable amount of vegetable matter in a state of partial decay, and known as humus, aiding the supply of nitrogen, and also such mineral matters as will supply the requisite potash, phosphoric acid, lime, magnesia, iron, sulphuric acid, and those mineral substances already referred to; for a soil to be fertile these must be in appropriate quantity, and in such condition that the growing plant constituting the crop can readily absorb them, and the varying fertility of soils depends, amongst other things, on the amount of available plant-food present. These mineral matters are usually present in the rocks from which the soils are derived: thus volcanic rocks contain ing felspar, ing weather ~~whether whole~~ or decomposed into clay; and the soil d thus formed is generally rich in potash. Marls, or chalky soils, frequently contain much phosphoric acid, owing to the presence of that substance in the

living animals whose remains give rise to this kind of soil.

The knowledge of the conditions influencing fertility constitutes a large portion of the science of agriculture; among the chief of these conditions are: 1. Weather, with its supply of rain, sunlight, and warmth. 2. Plant-food required by the particular crop under consideration,—in this case, the sugar-cane. 3. The condition of the land as regards what agriculturists usually know as heart.

In order to constitute what is known as good condition or heart, several things are necessary. It is essential that the soil be sufficiently loose and friable, that the roots may penetrate it with ease; the soil must also possess the power of retaining sufficient moisture to sustain the life of the plant, and at the same time must not retain too much, or it will become waterlogged, when most plants will refuse to grow in it. It is essential, too, that the soil contain air, for plants will only grow in the presence of air and will refuse to penetrate a soil whose pores are devoid of it, as in the case of wet or underdrained soils, where the growth is always checked. The influence of air upon root-growth is often well shown when roots obtain access to drains, the growth often being so abundant as to choke the drains.

These three conditions are favourably developed by the operations of ploughing, digging, or forking, the soil being loosened, the particles separated from each other, the capacity for retaining air and moisture much increased, at the same time that the removal of excessive moisture is facilitated.

The presence of humus or decayed vegetable matter is essential; this humus plays many important parts: in stiff clay soils it keeps the minute particles of the soil apart from each other, thus causing the soil to remain both friable and porous; in sandy soils it holds the particles together, thus giving the requisite coherence. Its presence assists the retention both of water and air, factors which have been shown to be essential to fertility. The correct appreciation of the part played by vegetable matter in the soil is of vast importance to the sugar grower.

The porosity of a soil which, as has been seen, depends largely on two things, tillage and humus, has a great influence on the retention of moisture during a dry season and its escape during a wet one. A compact, non-porous soil becomes much hotter under the influence of the sun's rays than does a porous one; consequently during a drought moisture is much more rapidly lost from a compact than from a porous soil. Further, in a compact soil moisture is drawn up from a considerable depth by capillary attraction;* in a porous soil, the air-spaces being larger, capillary attraction is lessened: hence a porous soil remains moist for a considerable time, while a compact one becomes dry and cracked. The importance of this fact can hardly be too strongly insisted on, particularly in tropical agriculture. A simple experiment clearly demonstrates the truth of what has been said. Into two tins of similar size and shape equal quantities of dry soil are placed,

* Capillary attraction is the force which causes fluids to ascend tubes or cavities of very small bore.

and an equal quantity of water added to each; the two tins and their contents are now precisely alike in weight and other conditions; one is left thus, but the contents of the other are closely pressed together, so as to imitate the condition of a badly tilled soil. The two tins are now exposed to the sun for several hours, care being taken that the conditions of exposure are equal; after a time they are carefully weighed to ascertain the quantity of water lost by evaporation. It will be found that the porous soil loses moisture much less rapidly than the other. The following results were obtained by the author in an experiment conducted as described:

TWO TINS, EACH CONTAINING 694 GRAMMES OF AIR-DRIED SOIL AND 100 GRAMMES WATER.

	Compact soil.	Loose soil.
Loss 1st day	24 grammes	19 grammes
Loss 2d day	15 "	10 "
Loss 3d day	8 "	7 "
Loss in 3 days	47 "	36 "

The loose soil at the end of three days has twelve and a half per cent. more moisture than the compact one.

It must also be remembered that in tropical and sub-tropical climates, during a period of drought, heavy dews are not uncommon; if the soil is porous a certain amount of moisture in the form of dew will be deposited in the soil itself, thus assisting plant-life at a critical time.

That a porous soil parts with its surplus water

more freely than a compact one, is self-evident and calls for no further comment here.

Porosity of soils, then, must be maintained by tillage and the introduction of vegetable matter as a means both of retaining the requisite quantity of moisture and of enabling the excess to drain away.

Plant-food in soils.—All plants appear to require essentially the same kinds of plant-food, but in varying proportions; the adjustment of the kind and quantity by artificial means constitutes the art and science of manuring.

Plant-food derived from soil may be classed as mineral and nitrogenous. The mineral matters found in plants are potash, lime, magnesia, oxide of iron, silica, phosphoric acid, sulphuric acid, chlorine (as chlorides), with others of apparently less importance, such as soda, alumina, manganese, etc.

Now, from what has been already said it is evident that, to be of value, these must exist in the soil in a form capable of being absorbed by the plant-roots; that is, they must be capable of being dissolved. It might therefore be assumed that the quantity of mineral matter available as plant-food in a soil might be easily estimated by finding how much was capable of being extracted by water. If the experiment be made, it will be found that little or no potash or phosphate, for instance, can be removed by treatment with water, even from soils bearing luxuriant crops; it follows, therefore, that the root must possess some solvent power not possessed by water, by which means it is enabled to dissolve and assimilate that portion of the plant-food insoluble in water. From

the root some acid exudation takes place, and this attacks the plant-food, dissolving it and fitting it for entrance into the root by the process of diffusion. This power is well shown by an experiment devised by Professor Sachs ("Text-book of Botany," first English edition, p. 625). If polished plates of marble or phosphate of lime are covered with sand to a depth of a few inches, and seeds are then sown in the sand, the roots which strike downwards soon meet the polished surface of the mineral and grow upon and in close contact with it. After a few days an impression of the root-system is found corroded in rough lines on the smooth surface; every root has at the points of contact dissolved a small portion of the mineral by means of the acid water which permeates its outer cell-walls.

The author, therefore, in the process of soil-analysis makes use of very dilute cold hydrochloric acid to extract the available mineral plant-food, believing that by this means he obtains a fair approximation to the process of nature.

The quantity of plant-food removed by a crop varies, as has been said; Warington gives the following quantities in pounds per acre.

	Weight of crop at harvest.	Nitrogen.	Sulphur.	Potash.	Soda.	Lime.	Magnesia.	Phosphoric acid.	Chlorine.	Silica.
Wheat-grain	1,800	33	2.7	9.3	0.6	1.0	3.6	14.2	0.1	0.6
Wheat, total crop	4,958	48	7.8	28.8	2.6	9.2	7.1	21.1	2.5	96.9
Barley, total crop	4,527	48	6.1	35.7	5.0	9.2	6.9	20.7	4.1	68.6
Oats, total crop	4,725	55	8.0	46.1	5.4	11.6	8.7	19.4	6.6	85.3
Meadow hay, total crop ...	3,360	49	5.7	50.9	9.2	32.1	14.4	12.3	14.6	56.9
Turnips, total crop.... ...	49,504	112	20.9	148.8	24.5	74.0	9.5	33.1	22.1	7.7
Potatoes, total crop	17,714	67	5.2	79.7	4.2	26.8	19.1	24.3	5.9	4.7

The weight of an acre of soil to a depth of nine inches is about 3,000,000, or 3,500,000, pounds; it will thus be seen that even a small proportion of plant-food will amount to a very large weight when calculated to pounds per acre; and this is important in considering chemical analyses, where the proportion of various constituents is often stated in parts per one hundred; thus one per cent. would represent 30,000 or 35,000 pounds, or about sixteen tons per acre to a depth of nine inches. The quantity of soluble matter shown by chemical analysis may often seem to be extremely small, and very accurate methods must be followed if trustworthy results are to be obtained. The following table gives some idea of the amounts of plant-food soluble in dilute acid, in the manner already alluded to, in the case of certain soils under cultivation in sugar-cane.

MINERAL PLANT-FOOD PER MILLION POUNDS OF SOIL, OR PER ACRE THREE INCHES DEEP, SOLUBLE IN DILUTE ACID.

Mineral substance.	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.
Silica (SiO_2)	970	1050	1010	6995	1323	1874	1776	1121	1028	?
Lime (CaO)	1932	2597	2538	4266	4420	4083	3810	5415	100000	400000
Magnesia (MgO)	300	400	320	1203	500	1934	760	980	100000	400000
Oxide of Iron (Fe_2O_3)	750	850	800	45	210	144	120	?	3650	3500
Potash (K_2O)	37	94	38	256	80	61	33	27	169	267
Phosphoric acid (P_2O_5)	47	28	28	65	36	37	70	18	185	87
Sulphuric acid (SO_3) .	trace									

I., II., and III., volcanic soils, Montserrat, W. I. IV., V., and VI., volcanic soils, Antigua, W. I. VII. and VIII., sedimentary, non-calcareous soils, Antigua, W. I. IX. and X., calcareous soils, Antigua, W. I.

Now, the undecomposed portion of the soil usually contains a very appreciable amount of plant-

food not readily dissolved by plant-roots, but which by the action of the atmosphere is slowly brought into such a condition as to be capable of being dissolved; we can thus divide the plant-food into that which is available and that which is slowly available. In a chemical analysis it is usual to regard those constituents which are insoluble in cold dilute acid, but which are soluble in warm strong hydrochloric acid, as slowly available. This slowly available plant-food is by no means to be overlooked in forming an estimate of the value of a soil, as it constitutes a kind of capital and indicates that soils possessing an abundant store will yield abundant crops with the minimum of manure, or of that special constituent which happens to be present. Below is given a comparison of the amount of certain substances soluble in dilute and strong acids, respectively, in certain soils.

	I.		II.		III.	
	Strong.	Dilute.	Strong.	Dilute.	Strong.	Dilute.
Lime	6460	5415	7770	6227	12820	5248
Magnesia	5514	283	3280	1380	13193	578
Potash	159	20	117	20	1340	~~130~~74
Phosphoric acid	146	43			209	129

Where no crops are removed from the soil, as in the case of forests and prairies, the fertility of the soil will actually increase from year to year, owing to the gradual conversion of the slowly available into the available mineral plant-food; at the same

time the decaying vegetable matter increases the humus and returns to the soil those mineral matters which entered into its own structure, thus increasing the soil's fertility. These soils are generally spoken of as virgin soils, and will often bear luxuriant crops for years without manures; but sooner or later they become more or less exhausted, and the art of the farmer is required, that by proper manuring they may be kept in a condition to produce remunerative crops.

The constituents of mineral plant-food which are usually first exhausted are phosphoric acid and potash. Hence the importance attached to the presence of these substances in manures. To these in certain cases may be added lime and iron.

Thus far attention has been directed to the mineral plant-food, there yet remains a great deal to be said on the subject of manures supplying nitrogen.

Nitrogen is an essential constituent of the food of both plants and animals, just as carbon and the various mineral constituents are. It has been seen how the mineral matters are obtained from the soil, and how the carbon is obtained from the atmosphere; now, four-fifths of the atmosphere consists of nitrogen, which would thus appear to provide an abundant supply of this important plant-food; yet it is found that plants cannot derive their nitrogenous food from the air, but that it all comes from the soil. (As to the nitrogen in the case of leguminous plants, see page 28.) All organic matter contains more or less nitrogen, and thus organic matters, such as animal excreta, pen manures, green dress-

ings, dried blood, etc., are nitrogenous manures, several of these being humus-supplying manures as well. The need for humus and its action on the soil has been already dwelt upon.

The various nitrogenous compounds in the organic substances, and in the ammonia salts above mentioned, are not in a fit condition to serve as plant-food without undergoing change; careful experiments have demonstrated that plants usually absorb their nitrogen in the form of a salt of nitric acid, or a nitrate, as it is termed.* Now, when organic matters or ammonia salts are mixed with soil, chemical changes take place, and the greater part of the nitrogen is converted into nitrate by a process very similar to fermentation. The researches of recent years—prominent among them being those of Warington, Schlösing, and Muntz—have proved that this conversion into nitrate is the work of a minute microbe or germ which is present in all fertile soil. This microbe is found in greatest number and in greatest vigour near the surface of the soil, and penetrates to various depths according to the character of the soil. For its active growth, and in order that it may carry on its useful function of converting organic matter into plant-food, several conditions are necessary: 1. A substance containing nitrogen and capable of being acted on by the microbe; such things as organic matter or

* Nitric acid is a compound of hydrogen, nitrogen, and oxygen, having the formula HNO_3; the hydrogen may be replaced by metals, as in the case of potassium nitrate or saltpetre, KNO_3, or sodium nitrate, $NaNO_3$.

ammonia salts fulfil this condition. 2. Air; and this is one of the reasons why tillage and working the soil increases the fertility, as it leads to more rapid nitrification. 3. Moisture. 4. A temperature of from 40° F. to 110° F., nitrification being most active at a temperature of about ordinary summer heat. From this it will be seen that the natural condition of affairs in the tropics — high temperature with abundant moisture—is conducive to rapid nitrification. 5. It is necessary that some base be present in the soil, *i.e.*, some substance capable of neutralising acids; in almost every case this condition is fulfilled by the presence of carbonate of lime or chalk, and this is one of the reasons why this substance is so important as a constituent of soils. It is very evident, then, that many of the points which were regarded as of importance in connection with condition or heart are those which are favourable to nitrification; and thus the theory of nitrification supplies us with a reason for performing many agricultural operations which previously rested only on a basis of tradition of successful practice.

The author has seen certain West Indian soils exceptionally rich in nitrogen, yet containing barely a trace of nitrate, owing to the non-fulfilment of some of the conditions given above, and this chiefly due to defective tillage and to the trampling of cattle on wet lands. In one instance a sample of soil which, when taken from the field, contained nitrate equal to only six pounds per million, after being kept in the laboratory for twenty-eight days, contained

nitrate equal to one hundred and thirty-three pounds of nitrate of soda per million, thus proving that condition and not manure was what this particular field lacked.

From what has been said, it follows that nitrate of soda is practically the only nitrogenous manure absorbed by the plant without having to undergo change under the influence of the nitrifying microbe.

Recent researches have led to the conclusion that plants belonging to the natural order *Leguminosæ*, which includes all plants of the pea and bean tribe, take up their nitrogenous food in a different manner from other plants; they can apparently freely assimilate nitrogen compounds other than nitrates, and it has been found that the weight of nitrogen in a leguminous crop may exceed the weight of nitrogen in the soil and manure used before the crop was grown. The inference is, then, that leguminous plants, unlike others, can make use of the nitrogen of the atmosphere. It is also found that leguminous plants have curious little swellings or nodules upon their roots, varying in size and shape on different plants; on the pigeon-pea (*Cajanus indicus*) these swellings assume large dimensions, sometimes being an inch or more in diameter. The internal structure of these nodules, as far as they have been examined by the author, appears to be as follows: There is an external layer resembling the bark of the root; immediately within this comes a cellular layer traversed by fibro-vascular bundles; in the centre of the nodule is a mass of cellular tissue (*a*, Fig. 6),

many of the cells of which contain starch; distributed throughout the central mass of tissue are a number of what the author distinguishes as "special cells" (*b*); these are usually rather large in size and do not contain starch, but are filled with countless bacteria or microbes. Not very much is known respecting these root-nodules, the active agents in which appear to be the bacteria or microbes; for the nodules do not form on the roots of plants grown in sterilised soil, that is, in soil subjected to such treatment, before the seeds are planted, as will destroy vegetable life, and that

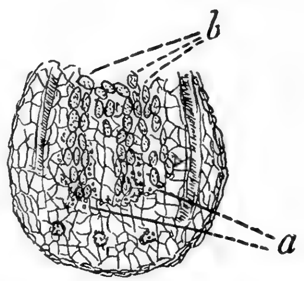

Fig. 6.—Section of root-nodule (magnified).

they will form if a little unsterilised soil be afterwards added to the sterilised. It has been assumed (for very little has been proved so far) that these bacteria, which appear to exist in all fertile soils, have the power of forming colonies on the roots of certain plants, and that so situated they have the power of assimilating atmospheric nitrogen; and that after its assimilation by the bacteria the nitrogen becomes available for the food-supply of the host on which the nodules are found. It has even been suggested that these bacteria are capable of assimilating atmospheric nitrogen without being associated with another plant. The increase of nitrogen in a leguminous crop renders these plants very valuable for the purpose of green dressing, as this will result in a gain of nitrogen to the

soil as well as a gain of vegetable matter or humus; whereas green dressings of other classes of plants merely restore the nitrogen taken from the soil.

It is found that some of the plant-food constituents of the soil are soluble in water, as for instance, nitrates and chlorides, and therefore these substances are found in the drainage-water; on the other hand, some of the constituents are insoluble, as potash, phosphates, and ammonia; these things are seldom found in drainage-water (see page 21). Pure sand possesses little or no retaining power for the various food constituents; and thus, if soluble phosphates, or potash salts, or ammoniacal chemical manures are mixed with sand, it is found by experiment that they are readily washed out by water. If, however, these substances be mixed with a good soil containing clay and humus, it will be found that they are not washed or removed by water. Potash, ammonia, and phosphoric acid are retained by soil by virtue of chemical action; precisely how this takes place is not clear, but the hydrated oxides of iron and alumina, the hydrated forms of silica and humus, doubtless play an important part in the process. (See Warington, "Chemistry of the Farm," p. 28.) The retention of the phosphoric acid is largely due to the oxides of iron and alumina and to lime; the potash is probably chiefly retained by humus and the hydrated silicates of alumina; the ammonia is chiefly retained by humus. In the case of potash and ammonia salts, it appears necessary that they should present themselves in the form of carbonates; if the sulphates, etc., of the substances be used,

they undergo decomposition with the carbonate of lime in the soil, forming carbonate of potash or ammonia and sulphate of lime, and the potash and ammonia in this form is retained by the soil. From this it will be seen how necessary it is to have a sufficient quantity of lime in the soil, and why marling tends to improve certain soils.

Now, for certain substances the soil possesses but little retaining power, such as nitrates and chlorides, and these substances are always found in drainage-waters; it will at once be seen that this fact has an important bearing on the application of nitrogenous manures. It will be remembered that all compounds of nitrogen are converted into nitrate by the action of the nitrifying organism of the soil, and now it is seen that soils have but little retaining power for nitrates; hence it follows that if heavy dressings of nitrogenous manures, particularly nitrates, are placed on the soil, there is a risk of loss by washing out in the form of nitrates, unless the substance nitrifies slowly and at about the same rate as the plant absorbs its nitrate. Nitrate of soda or sulphate of ammonia should therefore be applied in small quantities, at tolerably frequent intervals, while organic matter containing nitrogen, which nitrifies more slowly, may be applied in larger quantities and at greater intervals. In the tropics, the high temperature increases the rate of nitrification, and this, with the usually heavy rainfall, renders the risk of loss of nitrogen greater than in cold climates; hence the proper comprehension of the relationship of soils to nitrogen, and particularly to nitrified nitrogen, is a

subject worthy of attention and study on the part of all practical sugar growers.

Even if plant-food is present in sufficient quantity for the requirements of a crop, there are various circumstances, as we have seen, greatly influencing fertility; it is well known, for instance, that variations of the weather will cause greater differences in crops than can be obtained by manuring.

A soil must be capable of retaining plant-food and moisture, and thus, as shown above, must contain a due proportion of clay and humus. A clay soil, on the other hand, may become so close as to be unfertile, owing to the absence of sufficient air, so essential for root-growth and for nitrification, and also be so dense as to offer great resistance to the entrance of the fine, delicate root-tips and root-hairs. This question has been already discussed when treating of condition or heart (page 18).

It is important to remember that the points by which good condition is determined are such as do not admit of expression by figures in a statement of a chemical analysis; so that two soils may show a very similar chemical composition, yet differ materially in fertility, owing to difference in condition. In this the practical field observations of the planter are of great value, and chemical analysis can only supplement, and not supplant, this. The application of purely chemical manures to land in bad heart is a mistake frequently made, and tends to discredit the value of chemical aid in manuring. The planter should carefully avoid this error, the remedy for which lies in the correct exercise of his own judg-

ment. Chemical manures will only exert a full and beneficial action on soils already in good condition, but which are deficient in some one or more substances constituting plant-food ; and of these, phosphoric acid, potash, and nitrogen are those usually deficient, and which it is the function of the ordinary chemical manure or fertilizer to supply. The necessity for supplying other ingredients, such as lime, magnesia, iron, etc., is sometimes pointed to by special investigations, when the defect must be remedied.

Drainage.—When a heavy shower of rain falls, a certain quantity of water sinks into the ground, and when the soil becomes saturated—if the fall is more rapid than the absorption—a certain quantity flows over the surface and is carried away by the ditches and streams. If the rainfall continue for some time, the soil becomes entirely saturated, the water occupying the space previously occupied by air. Now, it has already been shown that this condition is highly unfavorable to the growth of such a crop as the sugar-cane, which, as with most other crops, requires a soil containing both air and moisture. It is necessary, then, that the excess of moisture be removed. Some porous soils are so situated that when the rain ceases they naturally part with their excess of moisture with sufficient rapidity to permit the entrance of the necessary air; such soils are said to possess natural drainage, and merely require attention to be directed to the channels for the escape of the surface water ; such soils, however, are not common. Other soils retain water for too

long a period, and are said to be cold or wet; this may arise from want of porosity, as in the case of stiff clays, or from a flat and low-lying situation, or more frequently from a combination of the conditions. The remedy for this lies in draining.

Draining may be accomplished by two principal methods—surface or open-trench draining, and subsoil draining. So far, in our West Indian colonies, the former method is the only one regularly practised, and the author's experience is that one of the real objects of the operation is frequently lost sight of or ignored. It is commonly supposed that surface drainage, as here accomplished, has for its object merely the removal of the superfluous surface water, and, that being accomplished, that it is well to leave the land wet. How erroneous this is has already been shown. It is necessary to remove all superfluous water to a considerable depth, so as to admit air, and thus—particularly on flat lands—it is desirable to dig the trenches to as great a depth as possible. The depth and distance apart of the trenches of course entirely depends on the nature of the land. A loose porous soil resting on a porous subsoil will only require such open trenches as will carry off the surface water during heavy rains. A stiff clay resting on an impervious subsoil will require close and deep trenching. The most convenient distance for trenches is thirty or forty feet apart, and in stiff soil they should be at least eighteen inches deep.

Open trenches, however, possess many and great disadvantages; and in countries where agricultural

practice has made any substantial advance, some form of subsoil draining is resorted to. If we dig down a sufficient depth into the soil we shall reach a level where the soil is always moist, except in periods of prolonged drought,—a level at which the amount of moisture is but slightly affected by the changes from wetness to dryness, etc., experienced by the soil nearer the surface; the pores of the soil at this level are practically permanently filled with water, and we may designate this the permanent water-level. The depth at which the permanent water-level will be met with entirely depends on the character and position of the soil; should it be at such a depth that there is ample room above it for the development in the overlying soil of the full root-system of the crop, then such a soil will not be benefited by subsoil drainage; it is drained naturally. But such soils are rarely met with, the permanent water-level is usually at no great distance from the surface, and it has been repeatedly explained that roots will only grow in soil whose pores are filled with air. The roots never grow down below the permanent water-level; if this is near the surface, it frequently happens that the depth of soil available for healthy root-development is far too limited to allow the growth of a full and luxuriant crop; consequently, if the season be a favorable one, the root-development being limited, the crop can only be moderately large; while, if the season be wet, the small depth of soil becomes waterlogged, and active root-growth is impeded; on the other hand, if the season be dry, the roots, having only a shallow range, soon lack mois-

ture and suffer from the effects of the heat of the sun. If, however, the permanent water-level be lowered by subsoil drainage, the roots have room for luxuriant growth, thus ranging over a greater space to absorb moisture and plant-food,—a state of things which soon shows an abundant result in the increased growth of the portion above ground, with its consequent increase of the crop. Again, a deep-rooted plant is much better protected against changes of season than a shallow-rooted one: in a wet season the porous upper soil absorbs a large amount of moisture which the subsoil drain quickly removes, leaving the soil in good condition for plant-growth; in a dry season the small amount of moisture from passing showers, dew, etc., is much more effectively retained, and the roots of the crop, having a deeper range, find a greater amount of moisture and are farther removed from the hurtful effects of the heat of the sun. The deep porous soil also retains a useful amount of moisture for a longer period than a shallow one. It follows, then, that subsoil drainage is beneficial, both in wet and in dry seasons.

Various methods of subsoil draining have been devised, all of which are carried out by opening a trench to the required depth of the drain, and placing in the trench something to leave a channel or waterway along the bottom when the earth is thrown back again into the trench. Many kinds of material have been used for this purpose, such as brushwood, loose stones, stones or brick or tiles roughly built to form a small culvert; and finally coarse unglazed earthenware pipes. This last ma-

terial has been found to answer most successfully; the other forms of drain are found, sooner or later, to become filled with earth and are thus rendered useless, whereas the earthenware drain-pipe properly laid will remain in good order for a long term of years, probably twenty or thirty.

The actual operation of laying tile drains in a piece of land is one which requires careful consideration beforehand, and if possible the work should be conducted by workmen having practical knowledge and experience of tile-laying. The points to be considered are, the size of pipe required, the depth of the drains, and their distance apart. For most work pipes having an internal diameter of one and a half inch will serve for the drains, and if these are connected with a main drain, as they frequently require to be, this main drain must be of sufficient capacity to remove freely all the water collected by the small secondary drains, and its size will be determined by their number. In laying tiles, levels are carefully taken, and trenches are opened, with specially shaped tools, to the required depth; care is taken that the earth at the bottom of the trench is disturbed as little as possible, all treading or walking in the trench being avoided; the tiles are laid end to end, and the joint is covered with a short length of pipe of larger size, as shown in the figure; the earth is returned to the trench and is firmly pressed down. It is desirable to leave the earth at the surface somewhat raised over the

FIG. 7.—Diagram of pipes and joints in tile drain.

trench, to prevent the surface water converting the trench into an open channel, whereby the drain is injured. Proper precautions must be taken to prevent the access of rats and other small animals to the drains. The danger of the drain silting up is avoided by a careful adjustment of levels, so that the water runs with equal velocity throughout the length of the drain, or perhaps, with advantage, with slightly increased velocity near the outlet. Silting up depends to a great extent on the relation of the size of pipe to the water flowing through it; a small pipe running nearly full not silting so much as a large one carrying only a small quantity of water. For details respecting tile draining the reader is referred to special works on the subject. For sugar-cane the author would suggest that the drains be laid about thirty to forty feet apart and four feet deep. This system of draining is somewhat costly, requiring a large outlay at first, and up to the present time it has been but little practised in the West Indies; in the sugar-growing districts of the United States it is being adopted with success, an example which should be followed by West Indian sugar growers; it is doubtless the way of preventing losses from short crops during droughts. It is difficult, in the absence of actual trials, to state the cost of such a system of draining in the West Indies, but there is little reason to doubt that it would prove remunerative, as it would increase the crop and at the same time decrease the cost of working the land; for the surface trenches would only require to be deep enough to deal with the surface

water, and would not be required to act as drains in the true sense of the word; this would reduce the cost of opening and cleaning out trenches, and greatly facilitate the cartage of the cane crop off the land; the work of ploughing would also be rendered easier, the deep trenches, frequently deepened and widened by the action of the water, offer serious obstacles to these operations, entailing considerable outlay, and rendering the work of the cattle and mules hazardous and cruel. With a system of tile draining it will doubtless be possible to cultivate the sugar-cane on land kept flat or nearly so, instead of being "holed" as at present, in which case the use of horse-hoes and weeding-machines will be possible, thus reducing the expenses incidental to the early stages of sugar-growing.

CHAPTER III.

Sugar-cane.—Preparation of Land, Planting, Manuring, Weeding.—Cutting Cane.—Methods of Dealing with the Trash.—Moulding.

HAVING briefly sketched the general principles on which a scientific system of agriculture should be based, it is now necessary to confine attention more particularly to the methods of cultivation employed in the case of the sugar-cane.

For several months the planter has been carefully ploughing and preparing the land to be planted, and in November or December the actual planting of the cane usually commences and is carried on for several months, so that there may be a succession of fields, one ripening after the other, in such a manner as to render the proper reaping and manufacture practicable.

On land of a fairly stiff character and lying somewhat flat, so as not to be subject to loss of surface mould by the rush of water during the heavy rainstorms of the tropics, it is usual to prepare the land in furrows and banks, an operation known as "holeing;" the furrows are generally four and a half feet or five feet from centre to centre, a distance of six feet being sometimes adopted; the banks vary in height, ranging from one to one and a half feet above

the bottom of the furrows. If farm-yard or pen manure is used,—and either this or green dressing is generally very necessary,—it should be well ploughed in during the preparation of the land for planting, preferably before the holeing or banking process. It is not an uncommon practice to defer the application of manure of this kind until the preparation of the land is completed, and often until after the cane has been planted. This is a mistake, as the function of pen manure is a double one: first, to supply vegetable matter to form humus, the importance of which has been fully dwelt upon and its action in loosening the soil explained; and it is as a mechanical manure, as a means of improving condition or heart, that pen manure is most useful; its second property, that of a fertilizer, is not to be overlooked, but is secondary to the one already alluded to; and it is to secure the full benefit of the first of these properties that complete covering and mixing with the soil is desirable.

Another method of preparing the land for planting, which has some good features, consists in cross-holeing; this differs from the plain holeing or banking in having a cross-bar raised at right angles to the furrow, thus forming a number of square holes, and in the bottom of each a cane-plant is placed. The use of cross-holeing appears to be twofold: in the first place it restrains the flow of surface water and prevents loss of mould by washing in heavy rain; if the land be sufficiently porous the water retained in the holes will soak through the soil and drain away without injury to the plant; on stiff land or in a wet

season there is some danger of waterlogging. The second beneficial effect of this operation is due to the extra tillage caused by the raising of the cross-bar, some increase of nitrification resulting from this. Some of these beneficial effects—probably all, and to a greater degree—could be obtained by tile draining with flat cultivation and machine weeding and tillage.

In whatever way the ground has been prepared, the next operation to be performed is the actual planting. For this purpose it is customary in the West Indies to use the upper part of the sugar-cane; this, as it contains but little sugar and a large proportion of glucose or molasses sugar, is useless for grinding, hence there is no loss of cane for seed or planting purposes. In some countries it has been the custom to employ the whole of the cane for planting, either laying whole canes in single or double rows in the furrows and covering them with earth, or planting short lengths of one, two, or three joints. As these methods of planting offer no advantages over the use of the top or end of the cane, there appears to be no reason why they should be retained. Some exercise of judgment is required on the part of the planter so to arrange matters that he may have canes to reap to supply himself with plant-tops at the required time, and in December and January it is not usual for the regular crop to be ready for reaping; it is therefore a common practice to leave a late field of canes as "stand-overs," or to allow a ratoon crop to grow for the special purpose of providing tops for planting. These ratoons are cut while probably the canes are but short, the

land is quickly broken up and planted, thus providing plants for itself and for other fields besides.

The plant-top consists of the three or four upper joints of the cane which are yet immature ; the leaves are cut off, leaving a piece of the cane about ten inches long, having two or three healthy buds or eyes. The plant-tops should be carefully picked over in order to reject any suffering from the attacks of borer or from any other disease, and as a precautionary measure they should invariably be soaked for a short time (an hour or two) in slaked lime and water, two pounds of lime to a gallon of water being a convenient strength ; this treatment destroys a great many animal and vegetable parasites, though unfortunately there are some, particularly the eggs of certain insects, which are not destroyed by it. In cases where diseases persistently attack the young plants the following method of treatment suggested by Dr. Bancroft is useful : Carefully clean the joints from all trash ; then immerse the plants in a mixture of carbolic acid and water heated to such a temperature as the hand can bear, using one pound of acid to fifty gallons of water ; allow the plants to remain in this mixture for twenty-four hours ; then immerse in a mixture of lime and water of the strength given above for a few minutes. Careful selection of plant-tops, followed by soaking in lime-water, greatly assists in securing an even, well-established growth of young canes.

In selecting tops for planting there are several points to remember. The upper portion of the top should be cut off sufficiently low down to cut out the

terminal bud, or when the top is planted the terminal bud will grow in preference to the lateral buds or eyes, giving rise to the appearance known as "capon tail," from the fact that the first leaves springing from the terminal bud have been partly cut off; the young leaves having thus lost their tips present a truncated appearance suggestive of a capon's tail. Plants grown in this manner do not bunch well, and the early developed cane arising from the terminal bud ripens before the other canes, and thus tends to arrow. Tops for planting should be taken from sound, ripe canes, those taken from sound but soft green canes rarely grow well. Mr. J. Sutherland was kind enough to make the following experiment at the author's suggestion: Three tops were planted in three tubs, care being taken to make the conditions equal in all three; two of the tops were from mature cane, and one was from young green cane. The two tops from mature cane sprouted in eleven days, while the immature one did not throw out a shoot until the twenty-second day.

Mr. E. R. Hall made the following experiment on the author's behalf: Three adjacent plots were planted, one with tops from ratoon canes, the individual tops being carefully picked in order to obtain those of a large size; the second plot was planted with selected small ratoon tops, and the third with good average tops from plant-canes; all these canes are now growing, and, so far as the eye can judge, there is no difference between them.

From these experiments, as well as from general experience, it follows that any good, sound, mature

cane will provide a top suitable for planting. On the other hand, it does not seem probable that the selection of tops is likely to lead to any improvement in the variety of sugar-cane; what is gained is a better growth and more certain establishment of the crop. This view is, perhaps, contrary to the ideas of some planters, but is proved by the following considerations: Under existing circumstances the tops used for planting are, on the whole, not from the best canes grown on the estates, being frequently taken from ratoons not considered worth keeping; hence it may be held, taking one field with another, that the tops used for planting are from canes in quality something below the best, and if the matter be looked at carefully, they will be found to be from canes below the average quality grown. Now, if selection of good qualities can produce improvement, selection of inferior kinds—and this is what the present method amounts to—should produce deterioration; yet it is not suggested that there is any falling off in the quality of the sugar-cane. The above is no argument for careless work, which will produce deterioration only too surely. The top planted reproduces the parent variety with all its characteristics; new varieties must be sought in canes from seed, or from occasional sports or bud varieties.

The plant-tops are planted in the following manner: The ground is marked out by means of a line and marks placed to indicate the spot where each plant is to go, the distances apart varying from four and a half to six feet according to custom (about

$4\frac{1}{2} \times 5$ feet or 5×5 feet being convenient and profitable distances). Some discussion has taken place recently as to the advisability of so planting that the plants, instead of occupying the corners of a square, shall stand at the angles of an equilateral triangle:

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*    *    *    *          *    *    *    *

*    *    *    *            *    *    *
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The diagrams will make this statement clear. By the latter method it is evident that for a given minimum distance between the plants the maximum number of plants per acre can be grown. To carry this into practice, the planting will require to be arranged as follows: if the distance between the plants, measured from right to left in the above diagram, be taken as 1, then the distance between the rows measured from top to bottom in the diagram must be 0.866; or if a uniform distance of five feet is required between each plant, then the plants must be five feet apart in the rows, and the rows four feet four inches apart, with the plants arranged in an alternate manner with those in the preceding row. When planting trees and the like, where the distances apart are considerable, this method is worth carrying out, but for cane cultivation it does not appear to the author to possess much merit. Regularity in planting greatly assists many of the subsequent operations of cane culture, such as weeding, manuring, etc., and is a great aid in detecting missing or weakly growing plants and admitting of healthy ones being substituted. The ground being marked out, a laborer, armed with an iron bar or

drill, makes a hole by thrusting the bar into the ground, then places a plant-top in the hole in such a manner that the head of the piece planted is just below the level of the ground, and then covers the whole by an adroit movement of the foot. In about seven to fourteen days the eyes or buds burst into leaf, and growth above ground fairly sets in; but before this the rootlets have commenced to grow from the double row of dot-like markings to be seen above each joint, thus the young plant obtains a supply of moisture and plant-food quite as soon as active transpiration and growth take place.

Various experimenters have recorded observations on the results of planting various parts of the cane, and also of selecting large or in other respects fine tops for planting. The results obtained do not appear to be definite; so far as the author's experience goes it would seem that any sound, healthy "top," which has not arrowed or flowered, is suitable for planting, and that it will reproduce the variety of cane from which it arose, with all its peculiarities, including the saccharine richness, etc.

When the young plants have just begun to spring is the most favourable time to apply manures containing potash and phosphates. It seems best, to the author, to apply at this time a mixture of sulphate of potash and superphosphate of lime, with lime, marl, or ashes, if the soil is at all deficient in lime. The quantities to be employed will vary with the soil, but generally two hundredweight of superphosphate and one-half to one hundredweight of sulphate of potash per acre will be found useful

amounts in the absence of any special information. This mixture should be evenly distributed in proper quantity on the surface of the soil, around and at a short distance from each plant; this is best done immediately before weeding, the operation of weeding tending to distribute the manure and to mix it with the soil. It will be observed that no nitrogen is recommended at this stage. If the land is in good condition, and has been treated in the manner described at the beginning of this chapter, there will be a sufficient quantity of nitrogen, and much of that nitrogen in the readily available form of nitrate, already in the soil. In about May or June, or earlier, if the growth of the plant shows lack of vigour, a light top-dressing of sulphate of ammonia in quantity of about one hundredweight per acre should be applied in the same manner as the superphosphate and potash, and a second dressing of the same quantity should be given six or eight weeks after the first; a third dressing is seldom necessary or remunerative.

It has been stated that ammoniacal manures should not be applied to soils containing more than 10 per cent. of carbonate of lime, as there is assumed to be a loss of ammonia owing to the conversion of the sulphate or other salt into the volatile carbonate of ammonia. The author recently made a series of experiments on two soils, one containing 1.3 per cent. and the other 40 per cent. of carbonate of lime. The soil was placed in a shallow glass dish, to a depth of about an inch and a half, a known quantity of sulphate of ammo-

nia was added in solution, and a definite quantity of water added. A very shallow dish, the bottom of which was moistened with sulphuric acid, was placed above the soil. Any ammonia escaping from the soil would be speedily absorbed by the acid.

Proceeding in this manner, and using one part of sulphate of ammonia to five hundred of soil, the non-calcareous soil gave off in two days ammonia equal in quantity to .017 per cent. of the sulphate of ammonia employed. The results in the case of the calcareous soil are given in tabular form below.

	500 grms. soil and .5 grms. s. ammonia.	500 grms. soil and .2 grms. s. ammonia.
Per cent. of added ammonia lost in first 2 days	1.10	0.90
" " " " next 3 "	1.02	0.60
" " " " " 3 "	0.72	0.41
Per cent. of added ammonia lost in 8 days	2.84	1.91

Now, as in all probability the loss is greater under the conditions of the experiment than it would be in the field, it does not seem necessary to abandon the use of sulphate of ammonia on calcareous soils, provided that they are in fairly good condition; in the case of poor calcareous soils containing but little vegetable matter, the loss would no doubt be much greater than in the above experiments.

The amount of various substances removed from the soil by a cane crop has been most carefully estimated by Professor Harrison. (See report of Dodds'

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Experimental Station, Barbados, 1889, etc.) He found the amount of phosphoric anhydride to range from 23.5 pounds with a crop of 22.3 tons of cane, to 45.3 pounds with a crop of 32.5 tons, per acre. The potash varied from 55.5 pounds with a crop of 28.5 tons of cane per acre, to 116 pounds with a crop of 38.8 tons per acre. These figures deal with the potash and phosphoric acid in the canes only, irrespective of the amount in the tops. The tops will contain about nineteen or twenty pounds of phosphoric anhydride, and seventy to seventy-five pounds of potash, but on a well-conducted estate these will ultimately find their way back to the soil after having been used for food for the working stock. A certain amount of the potash and phosphate, too, will be returned to the soil in the ashes from the furnaces and in the scums removed from the juice, so that, making allowance for these, the quantity of plant-food removed from an acre of land by an average crop of say twenty-five tons of cane per acre will be about fifty pounds potash, twenty-five pounds phosphoric anhydride, and seventy pounds of nitrogen per acre; these amounts of plant-food will be contributed to the soil by the methods of manuring here recommended, and this, with good and careful tillage, should, under reasonably favourable circumstances, produce satisfactory crops.

Weeding is an operation which will occupy much of the planter's time and care. This operation has a beneficial action for several reasons: not only are weeds killed and the ground left unencumbered for

the full growth of the cane, but the constant stirring of the surface-soil keeps it loose and friable, and the stirring of the soil distributes the manures, thus ensuring an even distribution. Weeding is generally done with the hoe. It would seem, however, as if a time were not far distant when this operation will be done by machines; this will result in more effectual stirring of the surface-soil, with its beneficial action, and will make the operation less costly. After the canes reach a certain height the operation of weeding becomes unnecessary, as the dense foliage of the cane effectually prevents the growth of weeds.

In some places it is the custom to remove the dead leaves or trash from the canes when they are nearly mature, in order to allow air and moisture to circulate more freely and thus hasten the ripening. In damp situations this operation is doubtless beneficial; how far it can be advantageously followed in dry places does not seem to be clear. The author is not aware of any systematic experiments undertaken to throw light on this subject; such experiments could be easily made and would be of interest.

When the canes are ripe, a fact which is ascertained by the cessation of growth, and in most varieties of canes by a tendency to deepen in colour, the reaping will begin. The canes are cut close to the ground, and the tops are cut off, the immature joints, containing but little sugar, are thus removed and are used for planting, the canes are tied in bundles and carried to the factory to be crushed.

If the roots from which the canes have been cut

are allowed to remain in the ground, a new growth of canes arises, and these are known as first ratoons, or second ratoons, etc., according to the number of growths thus raised without replanting. Except in soils of extreme fertility the yield of canes steadily diminishes by ratooning, so that on ordinary soils it is not profitable, as a rule, to grow more than second ratoons. In some districts the growing of ratoons is regarded with disfavour, and fresh planting is resorted to for every crop. The method of ratooning possesses some advantages, and, if the land is well tilled and cared for, would appear to be economical. One point requiring attention in ratooning is the effectual opening up of the soil to ensure the loose pulverulent condition essential to fertility. It is a good plan, as soon as the canes have been removed, to arrange the trash or leaf residues of the old crop on alternate banks, leaving alternate banks clear, then with a double-mould-board plough a good deep furrow is made in each bank free from trash; half of the trash is now placed in this furrow and the soil is drawn over it by means of the hoe; the remaining trash is buried under the other bank by a repetition of the process. The trash should be covered with soil as completely as possible, in order to promote decay; this decay taking place under the soil will keep it light and porous, thus rendering the operation of breaking up the soil of much more lasting effect than if no vegetable matter had been buried. All those parts of the field which have been much trampled in the removal of the previous crop should receive extra attention in the matter

of ploughing or forking to assist in undoing the harm done by compressing the soil and thus destroying its good condition.

The practice of burning the trash has been advocated and followed by some planters, under the impression that this renders the mineral constituents of the trash available as plant-food, and more particularly the potash. A moment's thought will show the fallacy of such a proceeding. The mineral constituents are present in the trash whether it is burned or no—the act of burning cannot surely be credited with creating the potash, even by anyone ignorant even of the simplest of scientific laws. If the trash decay in the ground, as it will speedily do, the mineral matters are then as available as plant-food as if the trash had been burned; nay, more so, for owing to the large proportion of silica present in cane-trash much of the potash is rendered insoluble by fusion with the silica to form a kind of glass; the phosphates, too, are rendered less soluble and so less active by burning. But the loss of the vegetable matter by burning is of the greatest consequence. The importance of vegetable matter in the soil has been so frequently insisted on in the foregoing pages as to require no repetition here. Sometimes, however, if the fields are badly infested with animal or vegetable parasites or diseases, it may be desirable to burn the trash in order to kill the harmful plant or animal (as various kinds of fungus, termites, mole-crickets, etc.), but this is evidently quite another question. Under certain circumstances it may be worth while to suffer some loss by burning

the trash for some gain in destroying certain pests, and the practical planter will readily discriminate between wise and unwise burning.

It is a common practice for planters to remove the fine mould accumulated in hollows and watercourses and return it to the land. There are several things to be considered in estimating the value of this practice. In the first place it is very necessary that ponds and watercourses should be kept from silting up, so that the accumulated mould must be removed at intervals; in the second place it is desirable that the soil washed from the fields should, if possible, be restored to them; again, it frequently happens that the soil in certain places is shallow, so that increased crops will result if by covering with mould an increased depth can be obtained. Mould obtained from watercourses and ponds often contains a fair amount of plant-food, but not to the extent which planters often think, and thus they frequently overestimate its value. The following analysis of mould from a watercourse, which was forwarded to the author as an illustration of a good mould, will prove instructive if compared with the analyses of soil given on page 23, when it will be seen that it is deficient in both potash and phosphoric acid.

Analysis of "Mould," Pounds per Million.

Silica	1,480	Oxide of manganese	900
Lime	3,836	Potash	41
Magnesia	1,350	Phosphoric acid	47
Oxide of iron	1,750	Nitrogen	1,687

The cost of removing mould and spreading it on the land is often very great, from £6 to £10 per acre

being prices commonly paid. It appears to the author that money is frequently wasted in this way; and it would seem best to use mould only when it becomes necessary to remove it for some other purpose than as a dressing for the soil, and to improve the soil by green dressings and better cultivation and manuring; this course will prove less costly and will be followed by better results, except where it is necessary to increase the depth of soil, as in the case where the soil is very thin.

CHAPTER IV.

Manures.—Farm-yard or Pen Manures, their Function and Use. —Management of Pen Manure.—Open and Covered Pens.—Green Dressing.—Chemical Manures.—Potash, Phosphates, Mineral Phosphates, Superphosphate, Basic Slag or Thomas Phosphate.—Nitrogenous Manures.—Sulphate of Iron.

A BRIEF summary of the manures commonly employed by sugar growers in the West Indies may prove of interest.

The excreta of the various animals kept on a plantation, together with their bedding, constitute one of the most important manures the planter can employ; this is known by a variety of names, as pen manure, farm-yard manure, etc. There are several reasons why this is of extreme importance to the planter. It must first be clearly understood that the function of pen manure is a twofold one: on account of the vegetable matter—derived from litter and uneaten and undigested food—which it contains, it is a manure by which condition is maintained, and this is probably its most important function; on the other hand it acts as a fertilizer on account of the nitrogen, phosphoric acid, and potash in it; this fertilizing property is of less importance than the former or mechanical manurial power, for nitrogen,

potash, and phosphates can be readily and cheaply supplied from other sources.

A curious fallacy exists respecting the action of the animal on the food, and the manurial value of the excreta as compared with the food eaten. It seems to be fully believed by many planters that the excreta have greater manurial value than the food. Nothing could be further from the truth. If all the excreta of an animal which had ceased growing were collected, the manurial value of these would be just equal to that of the food; there might be a little difference in the rapidity of the action, but the ultimate effect would be the same. How impossible it is to collect all the excreta will be immediately recognised. In the case of a growing animal the excreta will contain less potash, phosphates, nitrogen, etc., owing to the retention of these by the animal in order to build up new tissues in the form of bone, muscle, fat, etc. The following tables are taken from Mr. Warington's "Chemistry of the Farm," and are based on the experiments conducted at Rothamsted.

NITROGEN IN ANIMAL PRODUCE AND VOIDED AS URINE, FOR 100 CONSUMED AS FOOD.

	Obtained as carcase or milk.	Voided as solid excrement.	Voided as liquid excrement.	In total excrement.
Fattening oxen	3.9	22.6	73.5	96.1
Fattening sheep......	4.3	16.7	79.0	95.7
Fattening pigs	14.7	22.0	63.3	85.3
Milking cows	24.5	18.1	57.4	75.5

ASH CONSTITUENTS IN ANIMAL PRODUCE AND VOIDED, FOR 100 CONSUMED AS FOOD.

	Obtained as live weight or milk.	Voided in excrements and perspiration.
Fattening oxen..........	2.3	97.7
Fattening sheep	3.8	96.2
Fattening pigs.................	4.0	96.0
Milking cows	10.3	89.7

In these experiments very great care was taken to avoid loss of any kind,—such precautions as are impossible in agricultural practice. The following account of another series of experiments is taken from Dr. Griffiths' treatise on manures, p. 39:

" *The Muntz-Girard Experiments.*—Drs. A. Muntz and C. Girard ('Annales Agronomiques,' tome xii., 429–436) have performed a series of well-conducted experiments to establish the proportions of the nitrogen of foods stored up in the increase of live weight, that recovered in the manure, and also the proportion of nitrogen lost. The food given was weighed and analysed, the increase of live weight or the quantity of milk yielded during the experiments were noted, and the manure carefully collected and analysed. The following results were obtained:

	Kilograms.	Per cent.
Nitrogen consumed	21.817	
Nitrogen converted into flesh	4.3000	21.7
Nitrogen recovered in manure	5.588	19.72
Nitrogen lost......................	12.129	55.58

The experiments were conducted with thirty-two sheep kept in a fold with asphalt floor, so as to prevent loss of manure. Some of the loss of nitrogen is due to the escape into the atmosphere of ammonium carbonate.

"Muntz and Girard fed two Normandy cows each with 53.5 kilograms of lucerne and 49 kilograms of water daily. Each cow furnished 33 kilograms of solid excreta and 18 kilograms of urine. The weight of the animals increased by 15 kilograms during the experiments, and they yielded 361 litres of milk. With these cows the quantity of:

	Kilograms.	Per cent.
Nitrogen consumed	14.146	
Nitrogen assimilated as flesh	0.544	
Nitrogen assimilated as milk	2.560	21.95
Nitrogen in manure	7.461	52.75
Nitrogen lost	3.581	25.30

The loss of nitrogen is much less than in the case of sheep, due to the fact that the fermentation of cow's dung is less active, therefore less ammonium carbonate is formed.

"From these experiments it will be seen that farmyard manure does not return to the soil all the nitrogen which was originally extracted from it by growing crops. A portion goes to form flesh and milk, and another portion is lost in the form of ammonia."

From these experiments it will also be seen that pen manure is of somewhat less manurial value than the combined food and bedding from which it is de-

rived, even when preserved with the greatest care. It seemed necessary to the author to emphasise this statement, as he has so frequently heard planters talk of "keeping cattle to make manure," and heard objections to the use of tramways on sugar estates on the ground that the lack of pen manure under such a system would be fatal to successful management; and he has seen almost daily vegetable matter carted long distances to put into the cattle-pens when it should have been ploughed into the land on or near which it grew.

One important point of difference between farming in the tropics and in temperate climates may here be insisted on. In temperate climates it is desirable to have the farm-yard manure in a well-rotted state, in order that it shall act quickly when placed on the land. In the tropics decay takes place so rapidly that the rotting of the manure before application to the land is almost, if not quite, unnecessary; if this is recognised a considerable saving will result.

Of course, a certain quantity of pen manure must necessarily be produced from the ordinary working of a sugar estate. This is extremely valuable and should be preserved with all possible care. But to endeavour by forced means to "make manure" is a wasteful fallacy. The author's advice is to make the health and comfort of the animals the first consideration, giving them the most suitable food obtainable and adding enough litter for bedding to keep the pens dry and sweet; to apply this manure as quickly as possible, in good quantities at a time,

to the land in preparation for planting; and to thoroughly manure with green dressings all land not manured with pen manure.

The value of pen manure depends very largely on the manner in which it has been kept. Fresh manure has the highest manurial value, as, in rotting, a certain amount of nitrogen is lost, even under the most favourable conditions. If, in addition to rotting, the fluids from the manure-heap are allowed to drain away, then the loss becomes very great, as the nitrogen and potash are found largely in the fluid portion. If the heap be exposed to rain, so that every shower washes out the soluble portion, the loss may become so great as to render the remainder of little value as a fertilizer. Where possible, it is desirable to use pen manure as quickly as it is produced, and it has been shown that this can be done more readily in the tropics than in temperate climates. However, it frequently happens that the manure cannot be applied to the land directly, but must be kept for some time; and the value of the resulting manure largely depends on the way in which it is kept. In the West Indies it is the practice to herd the cattle at night in uncovered pens, into which large quantities of vegetable matter—in the form of cane-tops for food, and trash for litter—are thrown, so that a layer of manure of considerable thickness is soon formed. In many instances the drainage—and with the heavy rainfall of the tropics this is usually abundant—runs away without any attempt being made to preserve it; hence a large proportion of the nitrogen and potash is lost,

the remaining manure acting chiefly as a mechanical agent and possessing but little fertilizing power. When these pens are made in the fields, as frequently happens, it is advisable to lead the drainage from the pens in such a manner that it may flow over the land, and not find its way directly to the drains. A little care in this direction will prevent a great deal of waste which otherwise occurs. In the case of uncovered pens, not in the fields, it is well to have a catch-pit into which the drainage from the pen may run. The contents of this may be distributed upon the land at intervals. It is true that it is difficult to prevent the catch-pit running over in wet weather, so that this method only effects a partial saving at best; but still it is easily and cheaply carried out.

Covered pens are to be recommended, as by this means the manure is kept dry and free from drainage. It is no uncommon sight to see a cattle-pen half covered, and yet no provision exist to prevent the water running from the roof into the pen, when a small outlay for spouting would prevent the loss of much of the fertilizing portion of the manure-heap.

During the process of fermenting or rotting, the vegetable matter becomes converted into humus, and the nitrogenous portions into ammonia and ultimately into nitrates. If the fermenting heap become too hot—above 150° F.—there is considerable loss of nitrogen, and the heap should be watered with the fluid collected in the catch-pits. If the amount of vegetable matter or litter in the heap is too small—not a common danger in the

West Indies—there is some risk of loss of ammonia, and this condition is recognized by a strong smell coming from the heap. This may be corrected by adding more litter and covering with soil. The addition of soil to the pen from time to time is to be recommended, as soil is a useful agent in fixing ammonia.

The food upon which the animals are fed has a great influence on the value of the manure; indeed, in purchasing food-stuffs the farmer also largely takes into consideration the value of the resulting manures, and may be said to purchase his artificial manures in the form of food-stuff. This method of working is economical where cattle are raised for the sake of their milk or for the market, and the manure is carefully preserved, but becomes less economical in the case of sugar estates where cattle are used for draught purposes, with some necessary loss of manure, and where the system of keeping the manure is faulty. The sugar plantation too, if well worked, will provide all, or nearly all, the food required for its stock, and thus the importation of concentrated chemical manures becomes the most economical method of working. The following table, composed by Sir J. B. Lawes and Dr. Gilbert in 1885, gives the theoretical value of manure produced from the consumption of one ton of certain foods:

Linseed cake	£3	18	6
Cotton cake	3	8	8
Beans	3	3	5
Peas	3	2	6

Oats	£1	9	10
Wheat	1	8	7
Barley	1	6	1
Hay (clover)	2	1	3
Hay (meadow)	1	8	7
Mangels		5	0
Turnips (white)		4	0

In the following table analyses of farm-yard manure by various chemists are given:

COMPOSITION OF FARM-YARD OR PEN MANURE PER 100 PARTS.

	HARRISON.		VOELCKER.		ANDERSON.	WARINGTON.
	Open field pen.	Covered pen.	Fresh.	Rotten.		Average composition.
Moisture	49.89	45.64	66.17	75.42	72.48	65.0 to 80.00
Organic matter*	12.17	23.67	28.24	16.53	13 94	15.00 to 30.00
Phosphoric acid	0.14	0.29	0.32	0.45	0.31	0.2 to 0.4
Lime	0.95	0.72	1.19	1.78	0.59	
Magnesia	....	....	0.15	0.14	0.02	
Oxide of iron and alumina	15.30	12.61	0.42	0.67	0 45	
Potash	0.11	0.38	0.58	0.58	0.32	0.4 to 0.7
* Contains nitrogen	0.22	0.35	0.64	?	0.38	0.40 to 0.65

In applying pen manure to the land it is necessary to cover it thoroughly; this is best done by ploughing it in or by covering it during the process of raising the banks or "holeing:" unless it is buried its condition-giving or mechanical action, the importance of which must be recognized, is not fully exercised. The quantity to be applied should be about twenty tons per acre.

Where the quantity of pen manure produced on an estate is insufficient to cover the whole area to be planted, that portion receiving no pen manure

should be green-dressed, *i.e.*, a crop should be grown upon the land and turned in. This has been previously discussed in Chapter II., and it has been shown that plants of the pea and bean tribe (*leguminosæ*) are preferable for this purpose. When leguminous crops are grown and turned in, there is, as has been said, a gain of nitrogen; there is no actual gain in potash, phosphates, and other mineral matters, though this treatment will bring up mineral matters from below and deposit them near the surface in an available condition; hence green-dressing should be followed by a liberal manuring with the necessary mineral manures, potash, phosphates, and the like.

Amongst the plants suitable for green-dressing may be mentioned the pigeon-pea (*Cajanus indicus*), woolly pyrol (*Phaseolus mungo*), Bengal bean. These plants take from three to six months to grow to sufficient size to be ploughed in; when they are sufficiently developed they are cut down and arranged in rows to enable the plough to open furrows; the green dressing is laid in the furrows and covered with soil, the banks being raised over the green dressing.

In some cases where the soil is in very bad condition it is often expedient to raise a green dressing on the banks between the canes, even after the canes are planted and while they are growing. This may be done by planting pigeon-peas, woolly pyrol, or the like, upon the banks as soon after their preparation as possible; the green crop then grows up with the cane, and, if it be carefully watched, will

in no way interfere with the growth of the latter. When the green crop has grown as long as is considered prudent, it is cut down or pulled up and buried in the banks by the weeding gangs, who find very little difficulty in accomplishing this. By working in this manner even very stiff clay soils may be got into good condition in a comparatively short space of time. This method of working can only be followed advantageously in a moist season; in a dry season the double crop appears to remove too much moisture, and the cane crop suffers.

In some places seaweed can be readily obtained. This forms a valuable manure when ploughed in; by this means nitrogen and potash are supplied together with vegetable matter. About twenty or thirty tons per acre form an excellent dressing.

Now as pen manure and green dressings merely return to the soil for the most part potash and phosphates, etc., derived from the land itself, it follows that as the exported crops carry away certain quantities of various substances forming plant-food the land must be rendered less fertile from year to year, so far as mineral matters are concerned; hence it is imperative that manures supplying potash, phosphates, etc., be imported if fertility is to be maintained. Farm-yard manure alone is insufficient to maintain fertility.

The following brief sketch of some artificial or chemical manures may prove of interest.

Potash Manures.—Formerly potash salts were obtained entirely from the ashes of plants: in countries where forests prevail, as in North America,

Russia, Sweden, etc., large quantities of wood are burned for the sake of the ash; the potash is extracted from the crude ash by solution in water, and recovered by evaporation to dryness, the potash being thus obtained as carbonate. Of late years extensive mineral beds of salts containing large quantities of potash have been discovered in Germany, and it is from this source that the potash used for manurial purposes is chiefly obtained. One of the most important of these minerals is kainit, a substance containing sulphates of potash and magnesia together with common salt and other substances. A good sample of kainit should contain twenty to thirty per cent. of sulphate of potash; from this substance sulphate of potash in a comparatively pure state can be extracted, and where, as in the case of the West Indies, the manures have to be transported long distances, it is found more economical to purchase the purified and concentrated form of sulphate, although the first cost is higher. Thus, with freight at £2 per ton, if kainit containing twenty-four per cent. of sulphate of potash were purchased, the cost of the sulphate of potash would be increased by £8 per ton, while with purified sulphate of ninety-six per cent. the increase in cost is only a little over £2 per ton. This forms a very good illustration of what has been said before, namely, that in the West Indies it is economical to purchase manures in as concentrated a form as possible, and thus the use is denied to the planters of many forms of manure which in some countries are economical and useful.

Another mineral containing potash, and which is

often employed as a manure, is carnallite. This contains chloride or muriate of potash and chloride of magnesia. It is found, however, that it is preferable to employ potash salts in the form of sulphate rather than chloride, hence carnallite is not a manure likely to attract the attention of sugar-cane growers. Amongst the manures obtainable locally, wood ashes, leaves, etc., and urine are rich in potash, and should on no account be wasted.

Practically, then, the best form of potash manure to import is the sulphate ; this can now be obtained of a very high degree of purity. A guarantee as to the amount of potash it contains should always be required.

Phosphatic Manures.—The first phosphatic manure employed was bones, and bones are used at the present time when it is necessary to employ a phosphatic manure whose action shall extend over a long period. Raw bones contain about forty to fifty per cent. of phosphate of lime, and if they have been steamed or boiled to remove the gelatine, the quantity of phosphate of lime is raised to about sixty per cent., while the nitrogen, of which there is about four per cent. in raw bones, is reduced to about one-fifth per cent. Bones being very insoluble and thus requiring a very long time for their disintegration, a method was devised by Liebig by which they could be rendered soluble and so caused to act more quickly. He suggested the treatment of the bones with sulphuric acid. By this means an acid phosphate of lime is formed, together with sulphate of lime, or gypsum, and this in a little time forms

a dry mass which can be ground, and is then in a very suitable form for use as manure. Phosphate of lime submitted to this process is known as superphosphate.

Phosphate of lime suitable for conversion into superphosphate is found very widely distributed in nature, in the fossilized remains of animals and their excreta; of this character are the coprolites of the eastern counties of England, the phosphate beds of Sombrero, Aruba, Florida, Canada, etc. These mineral phosphates are found in various degrees of purity—from those containing seventy or eighty per cent. of phosphate of lime down to those containing a mere trace.

Good superphosphate should contain fifteen to twenty-four per cent. of the soluble or mono- or acid- phosphate of lime, as it is variously termed, equal to about twenty to thirty-two per cent. of insoluble or tri-calcium phosphate rendered soluble.

Finely ground mineral phosphates are sometimes used without being treated with acid; it is necessary that the substance be used in a state of very fine powder. In this condition good results have been obtained in the case of the sugar-cane. If lime be added to superphosphate, the mono-calcium phosphate is reconverted to tri-calcium phosphate. This is sold under the name of precipitated phosphate. Ground mineral and precipitated phosphates, from the fact that they are not acid, are well suited for soils containing but traces of lime.

Intermediate in character between natural manures and mineral phosphates are the manures known

as guanos; these for the most part consist of the excrement of various birds. Guanos vary in composition according to the length of time they have been deposited, fresh guano closely resembling farm-yard manure in its general character, except that it is extremely concentrated from the absence of litter; hence, guano of this type is a general manure, supplying nitrogen, phosphate, and a small quantity of potash. In the older guanos the ammonia has largely disappeared, so that these guanos are essentially phosphatic in their nature. Nitrogenous or ammoniacal guanos are becoming less and less abundant, so that much of the manure sold under the name of guano is a manure artificially compounded, usually being of excellent quality and preferable to raw guano.

There is one form of phosphatic manure which, so far, has received but little attention from West Indian planters,—basic slag, basic phosphate, or Thomas phosphate, as it is variously termed. In the manufacture of steel from cast iron some difficulty was experienced, owing to the presence of phosphorus in the iron. It is found possible to remove this by the use of lime, from which results the basic slag, a substance containing the phosphorus in combination with the lime as basic phosphate of lime. This substance contains from fifteen to twenty per cent. of phosphoric acid, equal to about thirty-four to forty-five per cent. of tri-calcium phosphate; hence, it is more concentrated than superphosphate. It is not an acid manure, as superphosphate is, and on soils deficient in lime, as so

many sugar soils are, there appears to be some advantage in this. It is very essential that basic phosphate be used in the state of the finest powder; when rubbed between the fingers, it should feel almost as smooth as flour. A guarantee of the quantity of phosphoric acid which it contains, and of its degree of fineness, should always be obtained from the vendor. This manure is cheaper than superphosphate. It can be stored without loss or deterioration for any length of time, and, as it is not acid, does not destroy packages as superphosphate does, whereby some loss of superphosphate is frequently incurred. It appears, therefore, well worthy of careful trials in the cultivation of the sugar-cane. The author has trial-plots manured with basic phosphate under observation, and the results appear highly satisfactory.

Nitrogenous Manures.—The chief nitrogenous manure used in sugar-growing in the West Indies is pen manure, and this is frequently increased in richness and value by feeding the stock on oil-cake. In a very few instances oil-cake has been applied direct to the land and serves as excellent manure. In districts—as in portions of the United States—where cotton-seed cake is easily and cheaply obtained, the plan of using oil-cake direct as manure may perhaps be followed with advantage, but in the West Indies such a course is hardly likely to prove economical, and cake is best used as food.

Practically the only nitrogenous manures it pays to import are nitrate of soda and sulphate of ammonia. These, from their concentration, are very

economical, the former, when pure, containing 16.4 and the latter 21.3 per cent. of nitrogen; hence the expenses in handling are reduced to a small amount, the point to be considered in colonial agriculture.

Nitrate of soda is found as a deposit in certain parts of South America where the rainfall is extremely limited; it is found mixed with clay, gypsum, and other impurities, and is purified by dissolving out the nitrate with water and recovering the nitrate by evaporation. Good commercial nitrate of soda as employed for manures usually contains from ninety-five to ninety-eight per cent. of real nitrate of soda. This manure is, as will be seen from what has already been said upon the subject of nitrification, a quick-acting one. It must be remembered that the soil has no retentive power for nitrates, hence in wet seasons or on wet lands there is great liability to loss from drainage.

Sulphate of ammonia is obtained from the ammoniacal liquor produced in the manufacture of coal-gas; it usually occurs in commerce in a very pure state, containing from ninety to ninety-eight per cent. of real sulphate of ammonia. It is sold on the basis of the ammonia it contains; thus twenty-four per cent. of ammonia is equal to ninety-three per cent. of sulphate of ammonia, while twenty-five per cent. of ammonia is equal to about ninety-seven per cent. of sulphate of ammonia. Like all chemical manures it should be purchased on the basis of analysis. Sulphate of ammonia is the most satisfactory nitrogenous manure the sugar grower can import; it should be employed as a top-dressing in

small quantities at a time, to obtain the best results; about one hundredweight per acre being a convenient quantity.

Ferrous sulphate, or sulphate of iron, is attracting some attention as a manure: the author has several trial plots laid down this 1891–92 season. In one experiment last season there was a most marked difference in the appearance of the canes manured with this substance; throughout the whole period of growth they were greener and taller than the adjoining canes—part of the same field—not manured with sulphate of iron, but otherwise similarly treated. Unfortunately, accurate quantitative results were not obtainable, but, as far as could be ascertained by weighing the canes from one-fifth of an acre from each plot, there was an increase of six per cent. in the weight of the canes in favor of the sulphate of iron, and this on second ratoons in a very dry season. The individual canes, too, from the sulphate of iron plot were finer looking. The juice from the canes manured with sulphate of iron and those not so treated was carefully analysed to discover if the iron exerted any influence on the juice; no difference could be detected. The figures obtained are given below.

	Cane-sugar.	Glucose.	Glucose ratio.
	Pounds per Gallon.	Pounds.	
Juice from canes with sulphate iron....	2.04	0.0378	1.85
Juice from canes without sulphate iron.	2.04	0.0373	1.83

These results agree within the limits of analytical error.

Sulphate of iron should be purchased in fine crystals or powder, and should be applied as a top-dressing in quantities *not exceeding* one hundred-weight per acre. Many sugar soils are deficient in soluble iron; under this circumstance the use of sulphate of iron is likely to prove beneficial.

No attempt is made here to discuss those manures not likely to be met with in the West Indies. In districts where manufacturing operations and the like are carried on, various waste products are obtained which are often of value as manure, but too bulky to admit of shipment to a distance; hence they are not referred to here. Nor is any attempt made to compare or contrast the merits of the many manures specially compounded for sugar soils; most of these are composed of mixtures of the various substances herein referred to, and as a rule are skilfully prepared and of good money value.

It is important to remember that artificial manures can only exert their full action on soils in good condition. To apply artificial or chemical manures to land in bad condition is a most wasteful proceeding, and one likely to lead to results discouraging to the experimenter and to the discredit of scientific manuring generally. Again, it must be remembered that artificial manures must be used in such a manner as will pay; it is quite possible—nay, easy—to employ these manures in excess, and thus to spend more money on the manure than the increase of the crop will pay for. Artificial manures are in most cases absolutely necessary. They are costly, hence their use calls for the exercise of a considerable amount of skill.

CHAPTER V.

Cane-mills.—Three-roller Mill.—Fletcher-Le-Blanc Four-roller Mill.—Mirlees' Four-roller Mill.—Skegels' Mill.—De Mornay Mill.—Hydraulic Attachment, etc.—Double Crushing.—Maceration.—Diffusion.

THE usual method of extracting the juice from the cane is to crush the canes between the rollers of various forms of cane-mill. The mills most commonly employed have three rollers, one roller being on the top and pressing on the two beneath, as in Fig. 8. The canes enter between A

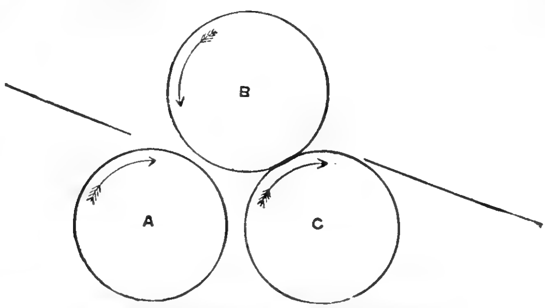

FIG. 8.—Diagram of three-roller mill.

and B, the feed rollers, and emerge between B and C, the megass roller. The distance between A and B is so arranged that the canes shall enter with sufficient freedom to ensure good feeding, and at the same time be subjected to a certain degree of pressure, while B and C are set as closely together as possible, leaving only sufficient space for the escape of the fibrous portion of the cane—the megass, or begass, as it is called. Skill is required in adjusting the rollers so as to secure as perfect

crushing as possible, and yet not endanger the safety of the mill by straining or breaking it from over-pressure. In the space between the rollers A and C is fixed a bar or plate—the trash-turner, or dumb returner, which serves to direct the crushed cane between the rollers B and C. The mass of crushed canes sometimes becomes jammed between the dumb returner and the rollers, leading to stoppage, and sometimes even to breakage, of the mill. Hence efforts are being made to construct mills in which the use of a dumb returner is dispensed with. Other mills are constructed with four or more rollers. Many kinds of mill have been designed, for each of which some special advantage has been claimed. Many of these are simply of the ordinary three-roller type, with various modifications in their construction to afford greater strength or security.

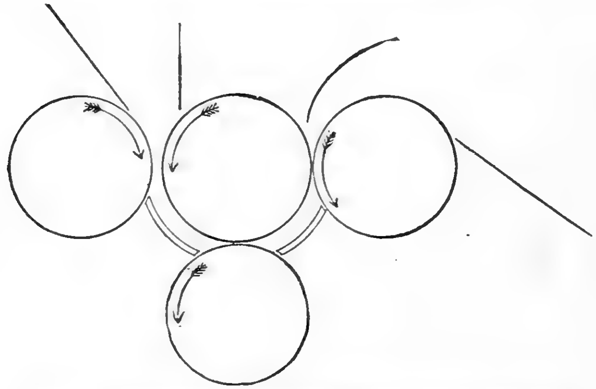

FIG. 9.—Diagram of Fletcher-Le Blanc four-roller mill.

Among those calling for special comment may be mentioned Fletcher & Le Blanc's four-roller mill, in which the cane is submitted to three crushings, as will be seen from the diagram, Fig. 9.

This mill is fitted with two dumb returners, which are hollow, to admit steam or water being forced into the megass, so as to combine the advantages of maceration with effective crushing.

In Mirlees' four-roller mill the cane is only submitted to two crushings, but from the construction of

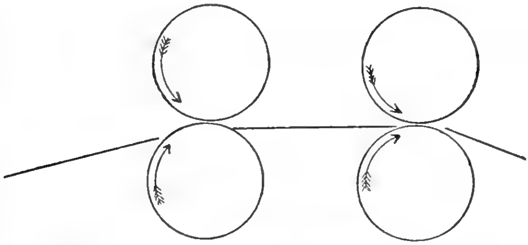

FIG. 10.—Diagram of Mirlees' four-roller mill.

the mill these can be made very effective, Fig. 10. This mill has no dumb returner. There is a disposition in some quarters to prefer mills of this type in which the rollers work in pairs, each pair only crushing once, instead of three rollers giving three crushings, as in the ordinary three-roller mill.

Messrs. Thompson & Black's auxiliary rollers, which can be fitted to any ordinary mill, are worth the attention of those whose mills are in fair order, but not powerful enough to give high expression.

The mill invented by Mr. Skegels, of Demerara, is attracting some attention, and reports of its working power are looked forward to with interest. It is a modification of the three-roller mill, and is without a dumb returner,* having besides some new features in its construction. In the De Mornay mill (Fawcett,

* A revolving bar or small roll is now added to take the place of a dumb returner.

Preston & Co., Liverpool) the trash turner is dispensed with. The mill has four rollers, two of which are large and two are small. The construction of the mill will be easily understood from the diagram, Fig. 11.

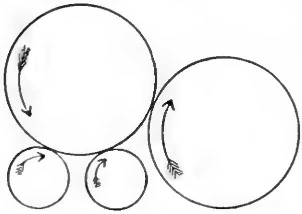
FIG. 11.—Diagram of De Mornay mill.

It would appear that dispensing with the dumb returner, and obtaining three distinct crushings of increasing power, the final one from the heavy rollers is an important advance in mill construction. Mills of the De Mornay type will doubtless find increasing favour in the near future.

Another important improvement in the construction of cane-mills consists in holding the rollers in place by flexible, instead of rigid, supports. In the older mills the rollers were held in place by means of screws passing into the framework of the mill, so that the rollers were kept almost inflexibly in one position—the result being that if anything, either cane or some foreign body, were forced into the mill in such quantity that it could not pass between the rollers, the mill must either stop—choke as it is termed—or something must break. It thus becomes a question of relative strength of mill and engine.

In improved mills the rollers are kept in place by what is known as the hydraulic attachment. This consists of a simple modification of the ordinary hydraulic press. It is well known that if pressure be applied to a fluid, the pressure is transmitted

equally in all directions, and thus if in any one place a pressure of say one ton per square inch be applied, then a pressure of one ton per square inch will be exerted at every part of its surface. If, then, weights be applied to the fluid in the vessel A until the pressure is one ton per square inch, and the vessel A is connected with a second vessel, B, by means of a pipe, then every part of the sides of the vessel A, of the pipe, and of the sides of the vessel B, will also be subjected to a pressure of one ton per square inch. Now, if in B there be a piston moving freely, the piston, too, will share the pressure. Suppose the area of the piston to be twelve square inches, then the piston will have a pressure of twelve tons exerted upon it. If, now, the piston be made to press upon the rollers, the

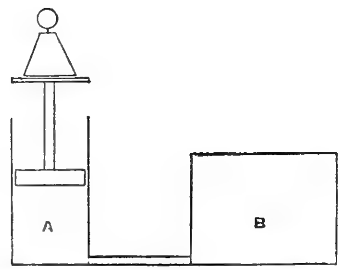

FIG. 12.—Principle of hydraulic press.

FIG. 13.—Diagram of hydraulic attachment to cane-mill.

rollers will be thrust forward with a pressure of twelve tons. How this is applied to the cane-mill will be seen from the diagram, Fig. 13; from which

it will be seen that with a piston at each end of the roller, and with the pressures mentioned, the roller so fitted will be held in its place with a pressure of twenty-four tons, no more and no less, so that no extra strain can be put upon the mill by over-feeding or by a foreign body, such as a stone. Hence the danger of breaking is reduced to a minimum. And what is quite as important, the same pressure of twenty-four tons is exerted upon whatever is between the rollers, whether much or little, so that the same pressure is exerted whether the mill is only partially filled with canes or when fed full. Those who have carefully watched how the crushing varies with the feed in a mill not provided with the hydraulic attachment will at once see the value of this flexibility with unvarying pressure.

Various devices have been arranged to apply springs in the place of the hydraulic press; some of these are very useful and easily attached to existing mills, and from their simplicity they have much to recommend them.

It is usual to speak of mills as expressing so much per cent. of the weight of the cane in the form of juice; it is well at the outset to see that this is an unsatisfactory method of statement, as canes will vary very much in the amount of juice which they contain, so that the same mill might express, say 65 per cent. from one lot of canes, and only 60 per cent. from another. A better method would be to ascertain the quantity of moisture left in the megass. This should vary less than the quantity of juice expressed.

How important good crushing is to the planter will be seen in a moment from the following figures: If one mill expresses 55 per cent. and another 70 per cent. from the same canes, then the gain is fifteen on every fifty-five, or 26.1 per cent. The average expression of what are regarded as fairly good mills in the Leeward Islands is probably not over 60 per cent.; the possible expression is certainly not under 75 per cent.; in other words, over 25 per cent. of the sugar now grown, and which with good machinery could be extracted, is at present thrown away. It is evident that this condition cannot last in these days of keen competition.

In large factories it is the practice to resort to double or even triple crushing; two or three mills are arranged one behind the other, the canes being thus submitted to two or three grindings. It is usual to blow steam into the megass in its passage from one mill to the other; by this means the extraction of sugar is increased. This would appear to be due to two causes: one, the dilution of the cane-juice, and the remaining moisture therefore containing less sugar; the second, that the cooking resulting from the use of steam or hot water coagulates the albuminous matter of the cane, and thus facilitates the expression of the juice.

It may be worth while briefly to sketch out here the principles on which the diffusion process of extracting sugar from the cane is based. Those who are interested in the practical application of the process will find abundant information in the current literature of the sugar industry, as in the

"Sugar-cane," "The Louisiana Planter," "Sugar," etc.

It has already been shown that by means of the process known as osmose (see page 9) certain substances—namely, those capable of existing in a crystalline form—can pass through vegetable membranes when those membranes are in contact with water on both sides.

Now, if thin slices of sugar-cane are placed in water, we have the vegetable membrane of the cell-wall separating water from the solution of sugar and other matters in each cell; consequently the sugar of the cell, being crystallisable, finds its way through the cell-walls into the water, and the greater part of the impurities, being non-crystalline, is left behind. By repeated treatment of the chips with fresh water, the whole of the sugar is removed.

In practice this is carried out by slicing the canes by means of revolving knives, and placing the resulting chips into large vessels into which hot water can be forced; the vessels vary in number from six to twenty, and are arranged either in a circle or in parallel rows. When the water has been in contact with the chips for a given time, it is drawn off. In order to effect complete extraction of the sugar, the water—or, as it may now be termed, diffusion-juice—is drawn down upon a fresh lot of chips, and another charge of water or weak diffusion-juice is run upon the partially exhausted chips. The juice in this way passes through all the diffusion-vessels in turn, water entering at one end of the series, and strong diffusion-juice being drawn off

at the other. The following diagram will help to make this clear:

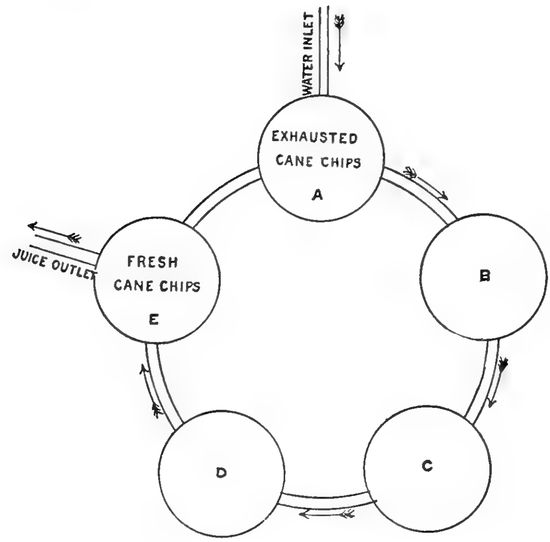

Fig. 14.—Diagram of diffusion-battery.

A, B, C, D, E are five diffusion-vessels. E has just been filled with fresh chips, while the chips in A are nearly exhausted. Hot water is forced into A, thence it passes into B, then into C and D, and finally comes in contact with the fresh chips in E, after which it is drawn off to the evaporators. The chips in A, being now exhausted by the fresh water, are discharged, and the vessel, refilled with fresh chips, now becomes the last of the series, the fresh water entering at B, and the diffusion-juice drawn off at A, and so on, each vessel becoming alternately first and last of the series.

The question whether diffusion is to supersede crushing is one which is being most vigorously dis-

cussed; the chief points for and against the process may be briefly summed up as in the table.

ADVANTAGES.	DISADVANTAGES.
Complete removal of sugar. Greater purity of juice.	Difficulty in slicing canes. Process and machinery complicated. Juice being diluted, cost of evaporation increased. Chips, being saturated with water, are unfit for burning without drying, hence ill adapted for fuel.

So far as the smaller sugar-growing colonies are concerned, diffusion at present appears to be quite out of the question. Even where it has been tried on a large scale in the West Indies its success has been in several cases problematical. Double or triple crushing is for the present the safest line on which to advance when all the circumstances influencing sugar growing in the West Indies are taken into account. This is no place for a lengthy discussion of the merits of diffusion as compared to crushing, and this brief outline must suffice.

CHAPTER VI.

Cane-juice.—Composition.—Tempering.—Use of Lime.—Phenol-Phthalein Test for Lime.—Clarifying.—Formation of Scum.—Treatment of Scum.—Filter-presses.—Composition of Filter-press Cake.—Uses of the Cake.—Value of Cake.

THE cane-juice as it runs from the mill may be regarded as a solution of sugar in water, with various impurities. It varies considerably in composition according to the variety and ripeness of the cane, the soil, the season, whether wet or dry, and numberless other circumstances. A fair sample of cane-juice will contain about

	Per cent.
Cane Sugar	17.5
Glucose	.5
Mineral Matter	.3
Organic Matter other than Sugar	.7
Water	81.0
Total	100.0

The organic matter other than sugar consists of albumen, fat, wax, colouring matter, and a variety of substances the properties of which are but little understood.

The juice is received into vessels termed clarifiers. These in the case of windmill estates are placed over the flues leading from the battery, and are thus heated by direct firing. On estates possessing steam plant the exhaust steam from the engine

is led into a steam-jacket surrounding these vessels, so that the juice is made hot as quickly as possible. Cane-juice is always slightly acid, so, as soon as the clarifier is about one-third or half full, a quantity of slaked lime, made into a thin cream by mixing with water, is thrown in, and the lime kept in slight excess until the clarifier is nearly full. When the clarifier is full the contents are vigorously stirred, and the quantity of lime carefully adjusted. This operation is known as tempering; its effect is to neutralise the acidity of the juice and to cause the precipitation of the greater part of the impurities.

Until recently this final adjustment of the quantity of lime was left to the unaided judgment of the workman in charge of the clarifiers. Consequently there was great irregularity in the manner in which the lime was used, sometimes an excessive, sometimes a deficient quantity being employed. As a rule an insufficient amount was used. The sugar thus produced of course varied considerably in quality. After a number of experiments, the author, in an article contributed to "Sugar," April, 1890, suggested a method of working which is now very generally followed on estates making muscovado sugar, with satisfactory results. The article is here reproduced:

"When using lime for the purpose of neutralising the juice of the sugar-cane and thus causing the precipitation of the albumen, some means of ascertaining with precision when sufficient lime has been added is highly desirable.

"To meet this requirement Dr. John Shier, many

years ago, devised a method of testing based on the use of litmus-paper as an indicator of the point of neutrality. It is found, however,—and Dr. Shier's directions for using his test contain a tacit admission of this fact,—that litmus-paper does not afford a correct indication of the point of neutrality in cane-juice; hence the test had to be supplemented by observations of the manner in which the flocculent precipitate of the juice separated. This complicates the working of the test and greatly impairs its usefulness. That litmus is not an accurate indicator in the case of organic acids is perfectly well known, and certain other bodies are now largely used in the laboratory in place of it.

"These considerations led the writer to make a series of experiments with other indicators, when it was found that phenol-phthalein could be employed with ease and certainty, and that it could be placed in the hands of the workmen in charge of the clarifiers, who quickly acquire the small degree of skill necessary for its successful use.

"The following are required for making the test: test-tubes, a pipette, and a drop-bottle containing a solution of phenol-phthalein in spirit; and the method of testing is as follows:

"The clarifier is filled with juice, and lime added in the usual manner. When the greater portion of the lime required has been added, a little of the juice is taken from the clarifier by sucking it into the pipette with the mouth; two of the test-tubes are about half filled with juice from the pipette, and one or two drops of the phenol-phthalein solution are added to

one of them. If sufficient lime has been used the addition of the phenol-phthalein solution will cause a slight change of colour to pink; if the quantity of lime is insufficient there will be no change of colour; in this case a little more lime must be put into the clarifier, care being taken that it is well mixed, and a fresh portion of the juice put into the tubes and tested as before; and this must be repeated until a very faint pink coloration is obtained. If too much lime has been used the addition of the phenol-phthalein solution will cause a strong pink to red colouration, and in this case the excess of lime must be corrected by adding a sufficiency of fresh juice until, on applying the test, only a faint change of colour is observed.

"This method of working has been employed successfully on several sugar estates, resulting in much more uniform work than has hitherto been obtained; it is also found that juice thus tempered gives very little scum in the subsequent process of evaporation, inversion is checked, and consequently the yield of molasses is lessened.

"To prepare the test solution, about ten grains of phenol-phthalein are dissolved in about half a pint of alcohol, white rum, or high-wines. The alcohol being frequently slightly acid, the acidity is neutralized by adding lime-water drop by drop to the solution until a faint pink colour makes its appearance and remains permanent. This faint colour is next destroyed by adding a small quantity of spirit until the colour just disappears; with good spirit the use of lime-water to correct acidity is unnecessary."

It may be added, as the result of longer experience, that it is a common fault, when using phenolphthalein for the first time, to add too much lime, thus obtaining a decided red instead of a faint pink colour when testing in the manner described. It is very important to avoid this. Every clarifier should be tested; it is not sufficient to test one or two in the course of the day's work.

Muscovado sugar tempered with the aid of phenolphthalein, taking care that only the smallest excess of lime is used, is firm and hard, delivers its molasses freely, and is usually somewhat dark with a greenish-grey colour easily recognized; this colour is easily removed in refining,—far more easily, in fact, than the colour of under-tempered sugars, which frequently have a red tinge.

The quantity of molasses produced is greatly reduced when this method of working is adopted, pointing to the fact that under-tempering leads to inversion.

This process has been found of great service to sugar-makers, as they are thus able to work with a degree of precision otherwise unobtainable, and are also able to keep a check on the workman, the process being rendered independent of the opinion or skill of the man in charge of the clarifiers. The author has received many gratifying accounts of the success with which the use of the process has been attended.

These directions apply to the manufacture of muscovado sugar: if a light-coloured sugar is required, it is advisable to under-temper somewhat, still using

phenol-phthalein as a guide ; or, better, to temper as for refinery muscovado, and, after clarifying, to boil to a density of about 20° B., and then subside,—that is, allow the syrup to stand for twelve hours, in order that any sediment may fall to the bottom of the tank, the clear syrup being removed by carefully drawing down, leaving the sediment undisturbed. After subsiding, the syrup is made slightly acid by means of sulphurous acid produced by burning sulphur and passing the fumes into the syrup. (See Chapter VII.)

Light-coloured sugar may also be made by tempering and clarifying in the usual manner, then rendering the juice slightly acid with phosphoric acid, various forms of which are now sold for this purpose.

In the analysis of cane-juice on page 85 there appears "organic matter other than sugar." This consists largely of albumen, a substance not unlike white of egg in character. On adding lime in proper quantity and heating this, albumen is thrown out of solution, and, as the liquid becomes hot, rises to the surface in the form of a scum.

It is well to remember why a scum forms. It is due to the fact that the heat drives out of the liquid a certain quantity of the air which the cane-juice contains in solution. The presence of dissolved air in the juice is readily understood if the foaming condition in which it leaves the mill is observed : this air as it is liberated attaches itself in little globules to the floating solid particles in the juice, the albumen, etc., and buoys them up to the surface, where a thick scum is formed. It will at once be seen that

to obtain a perfect scum it is necessary to leave the liquid undisturbed so that the minute bubbles of air do not become detached from the solid particles.

When the temperature is about five degrees below boiling-point it will be found that the liquid is almost clear, all the floating matter having been carried to the surface as scum. This is the point known as the "cracking point" by the work-people, as at this point the dark upper scum tends to crack and display a white frothy scum beneath. The juice is now ready to be drawn off: if this is done with care, the greater part of the juice can be drawn off clear, leaving a thick scum behind in the clarifiers; this scum is drawn off into another vessel, to be treated as described below.

On estates where rum is made, the scum is conveyed to the distillery and is used in setting up the wash for fermentation: many estates, however, from various reasons, have ceased to make rum, and on these it is desirable to extract as much sugar as possible from the scum; this is done by two methods. The first consists in accumulating all the scum obtained in a day's working in a steam-heated vessel termed a defecator or scum-heater, and the clear juice is run off from time to time. By keeping the scum until the following morning a considerable quantity of juice can be recovered, the residue after this treatment usually in practice amounting to four per cent. of the volume of the juice obtained from the mill.

In the second method the scum is submitted to

pressure in bags: at first linen bags were filled with the scum and pressed in various modifications of the presses used for cheese or cider making in England; these, although troublesome, yielded a fair quantity of cane-juice, and if carefully worked and kept clean did good service.

These presses are now entirely superseded by the various kinds of filter-press so largely used in almost every industry where filtration is necessary. The filter-press consists of a series of chambers, usually of iron. Each chamber is lined with a cloth. The substance to be filtered is forced into the chambers until they are all completely filled with compact and nearly dry solid matter, the fluid portion having meanwhile escaped through the cloth into suitable channels provided for it. The chambers are thus filled either by means of a pump, or preferably by means of the apparatus known as a monte-jus. This consists of a strong closed iron vessel provided with a pipe passing nearly to the bottom, and leading to the chambers of the press. A second smaller pipe just reaching through the top connects the vessel with a steam boiler. A third opening provided with a stop-cock serves to admit the scum. The scum is run in until the monte-jus is nearly but not quite full; steam is turned on, and the pressure of the steam forces the scum up the outlet pipe into the chambers, the pressure obtained being the pressure of the steam in the boiler. A pressure of from twenty to fifty pounds per square inch is found suitable for the working of filter-presses for cane-juice scums.

A great many filter-presses are on the market, all based on the principles here stated, but varying greatly in the details of their construction.

When sugar-cane scums are treated in a good filter-press with a pressure of about forty-five pounds per square inch, a very large quantity of juice is recovered, and there remains in the press a solid, nearly dry cake, which in practice is about one per cent. of the volume of the juice obtained from the mill. It is thus seen that a good filter-press effects a saving over the first method—whereby four per cent. of residual scum is obtained—of three per cent.

The following analyses of the scum-cake, after drying, will serve to show its general character:

COMPOSITION OF FILTER-PRESS CAKE, PER 100 PARTS.

	Harrison.	Watts.
Moisture	14.76	10.04
Organic matter*	66.93	68.45
Silica, sand, etc	3.20	5.40
Phosphate of lime	12.95	13.36
Oxide of iron	.92	.52
Alumina	..	.08
Magnesia	..	.22
Potash	.12	.15
Soda	..	.10
Matter not estimated	1.12	1.68
	100.00	100.00
* Contains nitrogen	2.07	1.91

The amount of phosphate of lime in the cake depends upon the manner in which the operation of tempering has been conducted. If the juice be un-

der-tempered only a portion of the phosphoric acid is precipitated, and the resulting scum will contain only a small proportion of phosphate of lime; if, on the other hand, the lime be added in sufficient quantity, practically all the phosphoric acid is precipitated, and the resulting scum is rich in phosphate of lime, as shown in the above analyses.

The quantity of sugar in the fresh cake is from two to four per cent., and, as the cake amounts to about one per cent. of the volume of the juice, the loss of sugar in the cake will be about one-fourth per cent. of the total sugar in the juice; or, say, from three hundred to five hundred pounds on a crop of one hundred hogsheads; whereas, if the scum thrown away were four per cent., as in the case of the defecator, the loss would be about three and one-fourth hogsheads. These figures will suffice to show the value of a filter-press.

The cake from the filter-press forms excellent food for cattle. The nitrogen present in the dried cake is equal to about twelve per cent. of albuminoids, being equal in quantity to that contained in such foods as oats and maize, and somewhat less than half that contained in linseed cake, peas, and beans.

When fresh, cattle will eat both the fluid scum from the defecators or the solid cake from the press with avidity. But owing to the rapidity with which it becomes sour, there is danger of producing colic in the animals unless the greatest care is taken. In the case of the defecator scum it is impossible to preserve it. Hence, only what can be eaten by the stock at once is of any use as food.

The remainder is generally run into the lees pond, where it undergoes fermentation, giving rise to most offensive smells and losing a considerable part of its manurial value.

The filter-press cake, on the other hand, can be dried, without difficulty, without fermenting, and, once thoroughly dried, it can be ground and will then keep for any length of time. It thus forms an excellent food for stock. When the practice of using scum-cake meal, as this may be termed, is introduced for the first time, it is well to mix it with other food, gradually increasing the quantity of the scum-cake from day to day. It may be given mixed with chaff and molasses, or mixed with molasses and given in the same manner as oil-meal. Cattle fed upon this, together with their ordinary diet of cane-tops or grass, fatten and keep in excellent condition and work well. No ill effects will follow from its use if care be taken to reject in the drying process any that is not perfectly sweet and good. By following this plan the quantity of oil-meal purchased on a sugar estate may be reduced, and in this way the filter-press effects another important saving.

In order to dry the cake, the author advises that, every time the press is opened, the softer portions of the cake, which will be found in the pipes, etc., of the press, be fed to the stock as soon as possible, thus getting rid of this, which it would be difficult to dry, and providing a considerable portion of the daily food. The firm cake should then be exposed to the sun, if the weather be dry, and the cakes

turned from time to time. At night, or in damp weather, the cake is broken into small pieces, say one- to two-inch cubes, and placed on shelves made of galvanised iron-wire netting of one-inch mesh. These shelves should be placed one above the other, about eighteen inches apart, and may extend from near the floor to the roof of the room they occupy. A free current of air should be maintained through the room, and rain be carefully excluded. When thoroughly dry the cake should be ground in a mill to a fine meal, and then may be stored in casks. It is advisable to spread the meal in a thin layer on a dry floor, and turn it occasionally, to dry it thoroughly, before packing it in casks. Thorough drying is of the utmost importance. It is well to have two hand-mills, one to break the cake into small cubes, and the other to grind the dry cake to meal.

The cake from the press is valuable as manure, and, after it has been eaten by the stock, a large proportion of the constituents of manurial value will be recovered, if the cattle-pens and stables are well arranged.

From the analyses it will be seen that as dried scum-cake contains about twelve to fourteen per cent. of phosphate of lime, and superphosphate contains thirty to thirty-three per cent., five hundredweight of scum-cake will be required to take the place of two hundredweight of superphosphate, and this will contribute about eleven pounds of nitrogen, equal to thirteen and one-half pounds of ammonia, or about half a hundredweight of sulphate of am-

monia; and thus five hundredweight will be worth about twenty shillings, or fully four pounds per ton, if used direct as manure.

What scum-cake is produced in excess of what the stock can eat should be ploughed into the soil at the rate of about five hundredweight per acre, or sold if a profitable market can be found.

The quantity produced will be roughly half a hundredweight per hogshead of sugar made. It will thus be seen that no estate can afford to be without a filter-press, and it is somewhat surprising to notice how slowly proprietors have placed them in their boiling-houses.

Of the nature of the colouring matter of cane-juice very little is known; it becomes darker when the solution is alkaline, and also when submitted to the oxidising action of the air; hence, when it is desired to obtain sugar of fine colour, it is necessary to render the juice slightly acid; and for this reason only those chemical agents which bleach by reduction are of any value in bleaching sugar solutions.

CHAPTER VII.

Manufacture of Sugar.—Inversion.—Open-fire Process.—Steam Pans.—Muscovado Sugar.—Vacuum Pan.—Method of Operating.—Triple Effect.—Centrifugals.—Production of High-class Sugars.—Use of Sulphur.—Carbonation.—Phosphoric-acid Process.—Animal Charcoal.

WHATEVER kind of sugar is to be made, the process of manufacture is practically that described in the preceding chapter, up to this point. From this point the processes differ according to the apparatus employed in evaporating the juice, and the kind of sugar produced. In general terms the process consists in evaporating the juice to a thick syrup and allowing the sugar to crystallise out.

A word upon the chemistry of sugar is necessary here. Cane sugar has the composition represented by the formula $C_{12}H_{22}O_{11}$, and if this be heated for a long time with water, H_2O, it is decomposed and forms another kind of sugar,—glucose or invert sugar, this change being represented by the equation :

$$C_{12}H_{22}O_{11} \quad + \quad H_2O \quad = \quad C_6H_{12}O_6 + C_6H_{12}O_6.$$

Cane Sugar and Water yield Glucose.

If any acid be present, this change takes place with very great rapidity, and this is one of the reasons for neutralising the acid of the cane-juice in

the operation of tempering. Various acids act with different degrees of rapidity. The mineral acids, as a rule, effect the change in a very brief space of time. The organic acids act much more slowly. This change of cane sugar to glucose is known as inversion, from the fact that cane sugar, when examined by polarized light, rotates the plane of polarization to the right, while invert sugar rotates it to the left. The art of the sugar-manufacturer consists in extracting the sugar from the juice with as little inversion as possible, for to inversion is due the production of molasses, with its consequent loss of sugar and loss of money, molasses being of small value. The chief agents causing inversion are acids, heat, and certain ferments to be referred to later.

The simplest method of manufacture consists in boiling down the clarified juice to a thick syrup in iron pans over a fire, and pouring out the syrup into shallow trays to crystallise. These iron pans are nearly hemispherical and are arranged in a series—usually of four or five—diminishing in size from the large one, into which the juice from the clarifier flows, to the small one in which the final concentration is completed. These pans are placed over a continuous flue, the fire being under the small pan, the object of this arrangement being to diminish as much as possible the time of final concentration; for as the syrup becomes dense it boils at a very high temperature, and therefore inversion proceeds with great rapidity.

This in effect is the common method of manufac-

turing muscovado sugar on estates not provided with steam machinery. Its chief defect lies in the fact that as the evaporation of the syrup is finished over the open fire there is considerable inversion: at the same time the process is difficult to control, hence the resulting syrup contains much glucose and is subject to great variation in density.

On estates possessing steam plant this process is modified by evaporating the syrup to a moderate degree over open fires, and finishing the evaporation in steam-heated pans. By employing this method the inversion is very much less than in the one just described, though even here the inversion is very rapid and has led to the abandonment of this method of working in those places where sufficient juice is dealt with to justify a large outlay for machinery.

To complete the description of the muscovado process: the syrup is boiled until the workman in charge of the pan judges by the manner in which the liquid boils that it is sufficiently concentrated, it is then run out in thin layers in coolers to crystallise. It is better to use a thermometer to ascertain the correct point at which to "strike" or discharge the contents of the pan. It is found that good results follow from striking when the temperature of the boiling mass reaches 238° to 240° F.; in this way much more regularity in the character of successive strikes is secured.

The coolers into which the concentrated syrup is run are usually about 10×6 feet and 2 feet deep; a number of these are employed, and the syrup is run into them in thin layers at a time. After being run

into the coolers the syrup is gently stirred at intervals to promote crystallisation. When the coolers are full, the crystallised mass is dug out and packed in hogsheads, boxes, bags, etc., in order that the fluid uncrystallised portion — the molasses — may drain out. This is aided by boring holes in the wooden packages to permit of the escape of the molasses. The polariscopic test of the sugar depends entirely on the extent to which the draining extends. The object of the sugar-maker, of course, should be to obtain a sugar testing as high as possible, and at the same time yielding the minimum quantity of molasses. Sugar in the manufacture of which much inversion may have taken place may yet test high by efficient draining, but at the same time an excessive quantity of molasses will be produced.

Muscovado sugar, by thorough draining, may be obtained testing as high as 94° by the polariscope. Good ordinary muscovado should test from 88° to 91°. Careful attention to the tempering and the correct "striking-point" are important factors in securing a high test. Care should also be taken that a sufficient number of free outlets are provided in the packages in which the sugar is cured: it is a good practice to burn the holes in the hogsheads, to prevent the fibres of the wood swelling up and closing the hole.

From a large number of analyses the author finds, on estates fairly conducted, that to make a hogshead of sugar of 2,000 pounds net and its accompanying molasses, — say about 30 gallons, — requires 2,600 pounds of cane-sugar in the juice. This on estates

having steam pans but not filter-presses; where filter-presses are used the quantity will be about 2,525.

The packages in which the sugar is placed to drain are arranged in a curing-house, the floor of which is furnished with beams or stanchions on which the packages stand, the molasses draining down onto a floor beneath, where gutters conduct it to molasses tanks, whence it is filled into puncheons for sale. The packages in which the sugar is cured are usually closed up and shipped without any further treatment; sometimes it is the custom to remove the sugar from the hogsheads or boxes and repack it in bags.

This is the outline of the process followed in making muscovado sugar for refiners' use. It will be seen that the process is simple, requiring neither elaborate machinery nor highly skilled labour; at the same time it is very wasteful. The rate of inversion may be judged from the following analyses: The samples in Series A were obtained from an estate provided with a windmill, the concentration of the juice being finished over the fire. The samples in Series B were from an estate having steam plant, the syrup being concentrated to a certain density over the fire, and the evaporation finished in a steam pan.

	Total sugar.	Cane sugar.	Glucose.	Glucose per 100 cane sugar.
A.				
Syrup, 1st copper..........	21.48	21.09	0.396	1.87
Syrup, 3d copper	39.88	38.94	0.942	2.44
Syrup, as struck...........	83.57	71.12	12.45	17.54
B.				
Sugar as supplied to pan ..	66 94	62.10	4.85	7.24
Sugar as struck from pan..	83.81	75.12	8.69	10.36

The last column gives the quantity of glucose in the syrup for every one hundred parts of cane sugar, or what is known as the glucose ratio.

In the case of the vacuum pan, about to be described, the inversion is but very slight. These results are expressed graphically in the diagram, curves representing the work of the vacuum pan and the concretor being added for comparison.

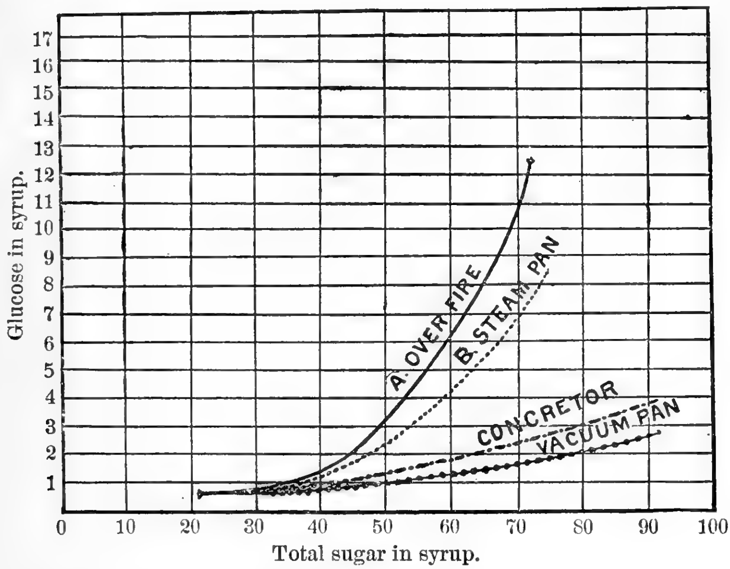

FIG. 15.—Curves illustrating the increase of glucose with increasing concentration in various processes of sugar-manufacture.

It is necessary here to say a few words on the theory of boiling. It is well known that the temperature at which a liquid boils depends entirely on the pressure to which it is subjected. The pressure to which liquids in open vessels are subjected is the pressure of the atmosphere, and this under ordinary conditions is a pressure of nearly

fifteen pounds per square inch. This is measured by means of the barometer, in which the mercury usually stands at a height of about thirty inches. From this it follows that a liquid boils at a higher temperature when the barometer rises, and at a lower temperature when it falls.

If, by means of an air-pump, the vapour be removed from above a liquid boiling in a closed vessel, the temperature of the boiling-point will be reduced, according to a well-known law. In the case of water, the following table gives the boiling-point under various pressures :

Temp., F.	Vacuum in inches.	Temp., F.	Vacuum in inches.
212°	0	130°	25½
200°	6½	125°	26
190°	10	120°	26½
180°	15	115°	27
160°	20	110°	27½
150°	22½	100°	28
140°	24		

Now, from the figures given in connection with the manufacture of muscovado sugar, it will be seen that it is the increased heat, as the syrup becomes concentrated, which leads to such rapid inversion and consequent loss. Hence, by boiling the syrup under reduced pressure we have the means of preventing this loss. This, in practice, is carried out by means of the vacuum pan (Fig. 16), which consists of a closed vessel, A, in which the syrup is boiled, the heat being supplied by a series of steam coils, B, at different heights. The steam, as fast as it is formed, is drawn off through the pipe, C, by means of the

air-pump, D, worked by a steam-engine. The steam is condensed as quickly as possible by being

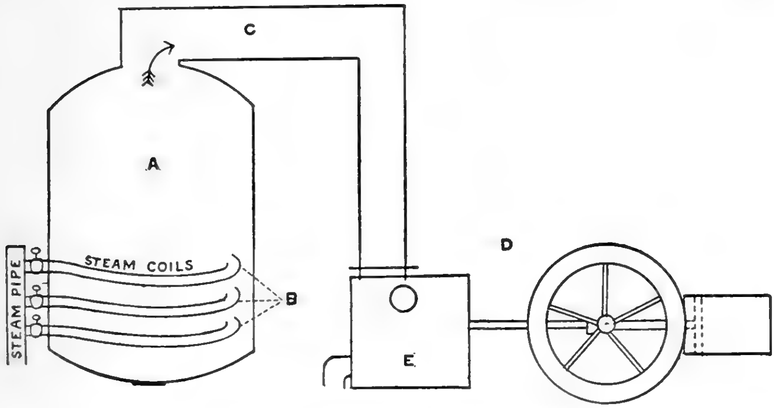

FIG. 16.—Diagram of vacuum pan.

brought into contact with cold water in C and E, the condenser. From the table of pressures and boiling-points on page 137, it will be seen that the more effectually the air-pump and condenser produce a vacuum in A, the lower will be the boiling-point of the syrup.

In practice, the pressure in the interior of the pan A is about one to two pounds less per square inch, instead of fifteen pounds as in open vessels, and the syrup boils at a temperature of 110° to 120° F. An additional advantage of this low temperature is that it allows the syrup to crystallise, or "grain," even during the process of boiling, so that the syrup, as discharged from the pan at the end of the operation of concentrating—*masse cuite*, as it is called—is a mass of crystals. On allowing this to stand for a few hours, further crystallisation takes place, and the mass is then ready to be cured.

A certain amount of skill is required to adjust the conditions during the concentration, that the crystals may be properly formed, and in this the art of the pan-boiler consists.

The following is an outline of the method of working: The air-pump is first started so as to create a vacuum in the pan; the cock connected with the syrup or feed-pipe is next opened, and syrup drawn into the pan in sufficient quantity to cover the lower steam coils; steam is turned on, and the syrup rapidly boils down. Fresh syrup is drawn in, in small quantities, from time to time, until the boiling mass begins to show signs of crystallising or graining. When this takes place the successive charges of syrup are admitted with care, so as to build up the grain slowly. Larger quantities of syrup being admitted at a time, as the pan becomes filled, and steam being turned on in the successive coils as the syrup covers them, the progress of the operation can be watched through sight-glasses let into the upper part of the pan. Small quantities of syrup can be withdrawn for inspection by means of an apparatus known as a proof-stick, an ingenious piece of apparatus fitted to every vacuum pan.

Attached to the pan are thermometers, by means of which the temperature of the contents of the pan can be ascertained. Vacuum gauges are also attached, which show the extent to which the pan is exhausted of air and vapour. The vacuum gauge indicates "inches of vacuum," or the height in inches to which a column of mercury would rise in a tube one end of which was connected with the

pan while the other dipped into mercury. If the vacuum were perfect, the mercury would rise to the same height as in the barometer, — about thirty inches. During the ordinary working of the pan the vacuum is about twenty-six to twenty-eight inches.

If the formation of grain be allowed to take place when only a small quantity of syrup is in the pan, this is known as "graining low down." It is often the custom not to allow grain to form until a considerable quantity of concentrated syrup is in the pan, and this method of working is known as "graining high up." By graining high there is some saving in time; but as a rule, particularly with small pans, the grain is not so large or so regular as when the syrup is grained low down. To obtain large and uniform crystals it is necessary to allow the grain to form slowly, admitting thin syrup in small quantities, and allow the boiling to take place slowly and steadily.

It sometimes happens from bad manipulation that the whole of the mass becomes cloudy from the formation of minute crystals. This condition of things, known as false grain, is to be guarded against most carefully, as it leads to considerable loss; the *masse cuite* under these conditions will not part with its molasses, and a sticky unsaleable product results. If the appearance of false grain be detected at once, the difficulty may be overcome and the false grain destroyed by admitting a considerable quantity of thin syrup into the pan and raising the temperature of the boiling syrup by wholly or partially destroying the vacuum for a short period.

This causes the minute crystals constituting the false grain to dissolve.

It is customary to discharge only a portion of the *masse cuite* from the pan and to take fresh syrup upon the remainder; this is known as doubling. By working in this manner the size of the grain is increased and some time is saved. Care is required in conducting the operation of doubling. Some syrup will get sticky after the operation is performed once, while in the case of other syrups it may be performed three or four times in succession. In doubling it is necessary to take in the fresh syrup to open up the *masse cuite* in the pan with the greatest care; if the syrup be admitted too rapidly false grain will result.

If a glance be given to the diagram of the vacuum pan it will be seen that the pipe C, conveying away the steam from the pan, must be heated to a certain extent, and the idea occurred to engineers that this heat might be utilised; the result was the invention of multiple-effect evaporation, a system in which a liquid is concentrated in a series of closed vessels, the steam from one vessel serving to heat the liquid in the next. It is evident that the pressure in the successive vessels must be gradually diminished, in order that the steam—having the temperature of the boiling liquid—from one vessel may be of a higher temperature than the boiling-point of the liquid in the next. The following diagram of a triple effect will enable the reader to follow the description of the method of working.

Juice or thin syrup is run into Vessel 1, and this is heated by means of a steam-drum supplied with

steam from some suitable source; the vapour or steam generated from the boiling juice passes by

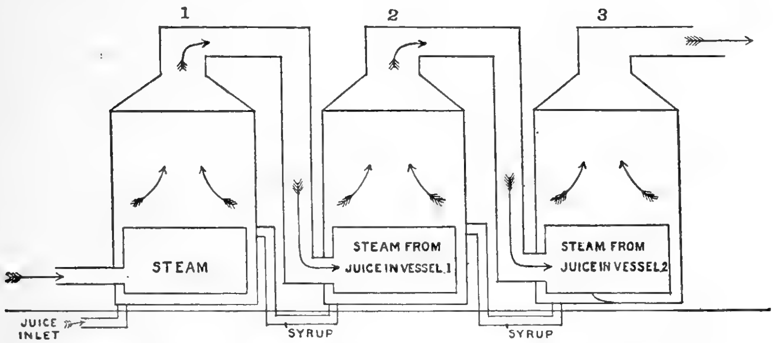

FIG. 17.—Diagram of triple-effect apparatus.

means of the conducting-pipe into the steam-drum of Vessel 2, and the steam from Vessel 2 passes into the steam-drum of Vessel 3. Now, in Vessel 1 the vacuum is but very slight, so that the boiling-point of the liquid, and consequently the steam produced, have a temperature of about 180° F., corresponding to a vacuum of about five inches; in Vessel 2 a vacuum of about fifteen inches is maintained, and in consequence the boiling-point in this vessel is about 150° F., so that there is a difference of 30° between the temperature of the steam and the boiling-point of the liquid, a sufficient difference to cause the liquid in Vessel 2 to boil, and thus supply steam at 150° F. to the steam-drum of Vessel 3, in which the vacuum is maintained at about twenty-seven inches and the liquid boils at 120° F. Thus the liquid in Vessel 3 is boiled by the steam from Vessel 2, which has a temperature 30° above the boiling-point of the liquid in Vessel 3. Suitable

air-pumps are attached to the apparatus, and pumps to remove the condensed water from the steam-drums, which, being under a pressure below that of the atmosphere, require to be pumped out, except in the case of the steam-drum in Vessel 1.

The syrup flows in a slow, continuous stream through the whole apparatus, and on the correct adjustment of the rate of flow depends the successful working of a multiple-effect apparatus. The syrup is concentrated in the triple effect to a sufficient density to be taken into the vacuum-pan, in which it is boiled to grain as above described.

The principle is the same whether the series consists of two, three, four, or more vessels. Various improvements in the details of the parts of the apparatus have been devised from time to time, in order to increase the efficiency or to render the working simpler.

In some of the most improved evaporators of this type the economy of working is very great, nearly forty pounds of water being evaporated for each pound of coal burned. It will be remembered that one pound of coal will convert only fourteen pounds of boiling-hot water into steam when the evaporation is accomplished in ordinary open vessels; indeed, this is the theoretical quantity, and in practice the quantity evaporated is very much less than this, usually not more than eight or nine pounds.

The latest evaporators aim at allowing the fluid to be evaporated to enter Vessel 1, and, after flowing over the steam-heated surface, to pass into Vessel 2, and over the heating surface of this into Vessel 3;

the evaporators thus contain but a small quantity of liquid at one time, but this passes through with considerable rapidity, a point of great importance in sugar-manufacture. The above statements briefly indicate the importance of the multiple system of evaporation ; and this system must in time replace the processes in use in the West Indies, if these islands are to compete successfully with other sugar-growing countries.

Curing Sugar.—In the case of muscovado sugar it has already been said that the only treatment to which the sugar is subjected to fit it for the market is to permit the uncrystallised syrup—molasses—to drain away through holes in the packages, a process which is very tedious and seldom complete. Where the crystals of sugar are of fair size, as in the case of vacuum-pan sugars or large-grained muscovado, the molasses is usually removed by the aid of a centrifugal drier.

It is well known that if any body be made to revolve rapidly there is a tendency for all the parts to fly outward from the centre ; this may easily be shown by twirling the handle of an umbrella between the hands, when the ribs will fly out. The same thing is seen in the governor of the steam engine, where the two heavy balls fly out from the centre as soon as they begin to revolve, and fly farther out the greater the speed at which they are driven.

The apparatus in which this principle is applied to the draining of molasses from sugar crystals consists of a shallow, circular drum or basket, closed at

the bottom and open at the top, the sides being perforated and constructed of various materials, either perforated copper or wire gauze, or some similar substance. This basket is capable of being revolved horizontally at a very rapid rate. The sugar, or *masse cuite*, is thrown into the basket, which is then made to revolve. The sugar soon flies from the centre and spreads itself upon the sides of the basket. Here its progress is arrested, but the molasses escapes through the perforations in the walls. The basket revolves in an iron casing which serves to collect the molasses, and from this the molasses is run into suitable tanks. After a few minutes' treatment in the centrifugal machine the sugar is freed from its molasses. If a fine-coloured sugar is required, it is the practice to wash the crystals during their revolution with a small quantity of water or bright syrup. In order to obtain a large yield of sugar it is advisable to allow the *masse cuite* to become cold before centrifugalling, as a considerable quantity of sugar crystallises out from the syrup during the process of cooling. Brighter coloured sugars can be obtained, though in somewhat smaller quantity, by centrifugalling the *masse cuite* warm.

The syrup or molasses thus drained from the crystals is usually boiled again in order to recover another lot of crystals. That this may be done successfully it is advisable that the syrup be used as quickly as possible, as any fermentation is very detrimental to the yield of sugar ; if it can be worked up as it leaves the centrifugals, so much the better. The syrup is mixed with sufficient hot water to re-

duce the density to about 20° B., and lime added, phenol-phthalein being used as an indicator; the mixture is heated in a steam-heated vessel or "blow-up," carefully skimmed, to remove impurities, and boiled to grain in the vacuum pan, yielding second crystals. It is often the practice to submit the syrup obtained by this operation to similar treatment, thus obtaining a small quantity of third sugar.

It is possible to obtain upwards of ninety-two to ninety-three per cent. of the total cane sugar in the juice in the form of crystallised sugar, and upwards of seventy-four per cent. should be in the form of first crystals. With good working the quantity of molasses should not exceed fifteen to twenty gallons per ton of sugar made.

Various processes are employed to produce sugar of fine colour direct from cane-juice. The one most commonly employed consists in decolourising the syrup by means of sulphurous acid. When sulphur is burned, pungent fumes of sulphur dioxide are given off, which dissolve in water, forming sulphurous acid. This substance has powerful bleaching action on most vegetable colouring matters and in the act of bleaching is itself converted into sulphuric acid. To apply this in the sugar industry sulphur is burned in a small furnace, and the fumes, urged forward by means of a steam jet, are brought into contact with the cane-juice, by which they are dissolved and which they decolourise. There is some difference of opinion as to the best time in the treatment of the juice at which to apply the sulphurous acid. Some apply it as the juice runs

from the mill, before tempering, while others apply it after tempering; the author believes that it is used to best advantage as late in the process of concentration as possible, say after subsiding or just before the syrup is taken into the vacuum-pan. If used early in the process there is danger of inversion from the presence of the sulphuric acid generated, while if used before tempering a good deal of the bleaching action is lost, as the solution must be slightly acid to obtain a fine colour, and efficient clarification cannot be obtained with acid juice.

In making high-class sugars it is usual to "subside," *i.e.*, to allow the syrup, boiled to a density of about 20° B., to stand for twelve hours, in order that the impurities may settle to the bottom. Bright juice, free from floating impurities, is thus obtained. No fermentation or inversion takes place if the process is properly conducted.

Decolourisation of the juice is often effected by forming a precipitate of some solid substance in the juice. The carbonation and phosphoric-acid processes may be taken as types of processes of this class; their success depends on the fact that precipitates tend to remove many kinds of vegetable colouring matter from solution.

In the carbonation process a quantity of lime far in excess of that required to neutralise the juice is added. This dissolves in the form of mono-saccharate of lime. Carbonic-acid gas is afterwards forced into the solution, which decomposes the saccharate, with the formation of cane sugar and carbonate of lime; the latter, being an insoluble sub-

stance, falls to the bottom of the vessel, carrying with it a considerable amount of impurities and colouring matter. The carbonic acid required for this process is usually obtained from the kiln in which the lime for the use of the factory is burned.

In the phosphoric-acid process, lime is added to the juice in somewhat larger quantities than is required to effect clarification in the ordinary way. After the removal of the scum, phosphoric acid is added to the juice, when an insoluble phosphate of lime is produced, which is best removed by subsiding; this precipitate carries down with it colouring matter and other impurities. Various forms of phosphoric acid are on the market, so prepared as to render them easy of carriage. The process is one requiring no special appliances, and is easily carried out.

The use of animal charcoal is but rarely resorted to in the colonies. For the removal of the colouring matter from the juice no other agent so completely decolourises sugar solutions. The difficulties attending its use are such as can only be successfully coped with when the manufacture is conducted on a very large scale. Its use is almost entirely confined to the process of refining. The charcoal is placed in iron cylinders 5 or 6 feet wide and 20 or more feet high. The juice after clarification is allowed to flow in at the top of the column, and after percolating slowly through the charcoal it flows out at the bottom in a colourless state. After having been in use for some time the charcoal loses its decolourising properties;

it is then reburned and after washing is again fit for use.

It is worth while remembering that only those bleaching agents that bleach by reduction are of value in the sugar industries. Oxidizing agents, which are frequently used as bleaching agents in other industries, do not bleach, but darken cane-juice and its products.

CHAPTER VIII.

Hydrometers or Saccharometers, and their Use.

THE sugar in cane-juice being subject to very great variation, it is convenient to have some means of ascertaining approximately the richness of the juice. This is usually done by means of the hydrometer, the use of which depends on the following points: When a solid substance, such as sugar, is dissolved in water, the density or specific gravity * of the solution is found to be greater than that of water, and increases in proportion to the quantity of solid substance dissolved; hence, if the fluid contain only one substance in solution, it is easy to ascertain precisely the amount dissolved by merely finding the specific gravity; but when the fluid contains two or more substances, this becomes quite impossible, as both have a similar effect in increasing the specific gravity, and it is impossible to say how much of the increase is due to one substance and how much to a second.

When any body floats in a fluid it sinks until the part submerged displaces exactly the same weight

* Density or specific gravity is the weight of any substance compared with the weight of an equal volume of water taken as unity.

of fluid as the body itself weighs ; thus any floating body will be more or less submerged as the fluid in which it floats is less or more dense. This principle is applied to the construction of hydrometers, which serve to measure the density of fluids by the depth to which they are submerged when they are floated in the fluid. Hydrometers are usually made of the form shown in the figure, and may be of glass or metal; a scale marked on the stem measures the amount submerged, and thus the density of the fluid. Hydrometers are made with scales of various values, according to the uses for which they are to be employed.

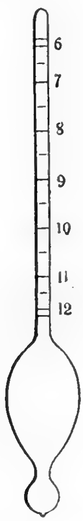

Fig. 18.—Beaumé's hydrometer or saccharometer.

The hydrometer commonly used on sugar estates is graduated with the scale known as Beaumé's. In the table on pages 139 and 140 is given the quantity of sugar in solution corresponding to the various degrees Beaumé.

For use in the West Indies it is most convenient to have the hydrometer graduated to indicate from 6° to 12° B., this range covering the variations of ordinary cane-juice, and on an instrument thus graduated the marks are sufficiently wide apart to admit of their being read with considerable accuracy. The use of instruments having a scale ranging from 0° to 50° or 60° B. cannot fail to be mis-

leading. The instrument should be graduated at a temperature of 84° F.; sometimes instruments are found graduated at 60° F., the temperature employed when they are to be used in a cold climate; the readings of such instruments may be corrected by noting the temperature of the liquid tested and adding .0265 for every degree F. above the temperature at which the instrument is graduated, or one-tenth for every four degrees difference of temperature.

Another hydrometer, known as Balling's or Brix's, is commonly employed in the sugar industry. The readings of this scale indicate the percentage of sugar present in solution; thus 14° Balling indicates a solution containing fourteen per cent. of sugar.

From what has been said it follows that, when applied to cane-juice, the quantity of sugar can only be estimated approximately by the hydrometer, which is unable to distinguish between cane sugar, glucose, or other dissolved substances.

In ascertaining the density of cane-juice, it is the common practice to take the juice as it comes from the mill, and to put the hydrometer into this; this method involves several sources of error. Owing to the presence of air, the fluid appears to be lighter than it really is, and by taking a series of observations on the same sample in rapid succession, a number of increasing densities will be obtained; at this stage, too, the juice contains in solution a quantity of organic matter other than sugar, which is shortly to be removed in the process of clarification.

When the instrument is used as a saccharometer it is preferable, then, to take the density after clarification, when the air and a considerable quantity of impurities have been removed. To do this, a sample should be taken from the clarifier and rapidly cooled by pouring into a shallow metal dish floating in water; when cooled, the juice is poured into a deep narrow vessel, and the density taken; the temperature of the liquid being noted, and a correction made if the temperature differ from that at which the hydrometer is graduated. Much more trustworthy results are obtained by this method, as the density is taken in juice containing much less impurities and free from air.

The following method of using the hydrometer may be found useful in muscovado boiling-houses, where chemical control is rarely obtainable; in larger factories more accurate methods are usually employed. By taking the density in the manner directed, and calculating the amount of sugar present in the juice from the table, the planter can ascertain approximately how the work of the boiling-house is being carried on; for, by dividing the total pounds of sugar by 1.3, he will obtain the number of pounds of cured muscovado sugar which should be made. This, of course, will only be approximately true, but, being so easily carried out, serves as a useful control. It is advisable to make a deduction of seven or ten per cent. from the total sugar in the case of young canes, or of three per cent. in the case of sound ripe canes, on account of the glucose, etc., present.

The following example will explain the method:

		Pounds per gallon.	Pounds.
5,000	galls. juice at 10° B., corrected,	= 1.9396 =	9,698
4,000	galls. juice at 11° B., corrected,	= 2.1513 =	8,605
9,000			18,303
	Less 3 per cent		549
	Pounds sugar estimated		17,754
	Divided by 1.3		13,657

The 9,000 gallons of juice should therefore produce 13,675 pounds of muscovado sugar, or 6.8 hogsheads of 2,000 pounds net; or 1 hogshead from 1,176 gallons of juice.

It will be found instructive to test each week's working on the above lines. Careless working or waste will be thus detected.

CHAPTER IX.

Molasses.—Production, Composition, and Uses.—Recovery of Sugar from Molasses.

MOLASSES will vary very greatly in character according to the manner in which the sugar from which it drains has been produced. That produced in the manufacture of muscovado sugar without steam pans will frequently be dark in colour from slight charring. When steam pans are used the colour is usually improved, the composition remaining about the same. When the vacuum pan is employed, the cane sugar is usually more perfectly extracted, so that vacuum-pan molasses contains much more glucose and impurities than molasses obtained in the muscovado process.

The following analyses may be taken as representing the various qualities of molasses:

	Muscovado molasses.	Vacuum-pan molasses.
Cane sugar	40 to 50	30 to 40
Glucose	15 to 25	20 to 35
Mineral matter	2 to 6	5 to 8
Organic matter other than sugar	3 to 10	10 to 20
Water	20 to 30	20 to 30

The quantity of molasses made per hogshead or per ton of sugar also varies greatly, and depends

both on the quality of the juice and on the skill of the sugar-manufacturer.

The production of molasses or uncrystallizable syrup is due to the fact that glucose, mineral matters, and organic impurities other than sugar, prevent the crystallisation of cane sugar. Hence the quantity of molasses will be greater in proportion to the quantity of these substances present in the juice. But by far the most important agent is the glucose formed by inversion during the process of boiling; so that it is at once seen that, not only does the formation of glucose mean the loss of so much cane sugar by inversion, but also the further loss of another portion by preventing its crystallising. In careful working with vacuum pans it is found that one part of glucose prevents the crystallisation of an equal weight of cane sugar. In the molasses of the muscovado process the proportion of cane sugar to glucose is much greater than this.

The quantity of molasses produced in the muscovado process is largely dependent on the manner in which the process is conducted. It varies from 30 to 50 gallons, or more, per hogshead of 2,000 pounds. There are two points by attention to which the quantity of molasses can be kept low,—care in tempering, and brisk boiling in the steam-pan; long-continued boiling of concentrated syrup is one of the greatest producers of molasses.

In the vacuum-pan process the yield of molasses depends chiefly on the amount of impurities in the juice, inversion during manufacture in this case being but slight. Where only first and second

sugars are made, the quantity of molasses will vary from 10 to 20 gallons per 1,000 pounds sugar produced. But where third sugar is made from the molasses, the quantity may be reduced to from 5 or 10 gallons per 1,000 pounds of sugar produced.

After the molasses has been made, considerable loss is often experienced from fermentation. The packages overflow, and often arrive at their destination nearly half empty. It is believed that this could be remedied by heating the molasses to about 200° to 212° F., in order to destroy the germs to which fermentation is due; a clarifier or steam pan would afford a means of doing this.

The question arises, What is to be done with the molasses? In the case of muscovado molasses of good colour and flavour, there is a ready outlet as a food material, and this doubtless has enabled the wasteful muscovado process to hold its own in the West Indian islands for so long, the value of the molasses with a steady demand, together with the small cost of the machinery and appliances, rendering it suitable to the small-estate system so general in these islands.

With molasses of inferior quality, and vacuum-pan molasses, from which so large a proportion of sugar had been extracted, leaving a high percentage of impurities, the case is different. Molasses of this kind may serve as food for cattle, pigs, etc. But its value is so small as to scarcely counterbalance the cost of packages, freight, and other expenses. No doubt the right use to which to apply it is to convert it into alcohol, though the excise regulations of

some colonies impose difficulties which render the use of small stills on small estates unremunerative. One or more large distilleries in each colony would probably be able to overcome these difficulties.

Many processes have been suggested, from time to time, for dealing with molasses. These, however, apply almost exclusively to the molasses of beet sugar, and it will be seen that it will not pay to apply any of these processes to the molasses obtained from the sugar-cane. These processes have for their object the recovery of sugar, or the recovery of potash, or both. Several processes for the recovery of cane sugar depend on the fact that this substance will combine with lime, strontia, etc., to form a compound insoluble in water, while glucose will not. The glucose is separated by washing the precipitate or sediment with water, and the cane sugar recovered by treating the insoluble compound with carbonic-acid gas, which converts it into carbonate of lime or strontia, insoluble in water, and sugar which dissolves. Now, beet molasses contains far more cane sugar than molasses from the sugar-cane, and but little glucose. An average sample of beet-molasses will contain:

Cane sugar	50
Glucose	1.5
Mineral matter *	12
Organic matter other than sugar †	16.5
Water	20
Total	100

* Contains potash = 5 per cent.
† Contains nitrogen = 1.5 per cent.

The value of the sugar recovered will be insufficient to make processes of this character remunerative in the case of sugar-cane products.

Beet molasses contains a very large quantity of potash,—on an average four or five per cent. On mixing molasses of this character with sulphate of alumina, a considerable quantity of alum, which is a double sulphate of potash and alumina, crystallises out. Processes of this kind have been worked successfully, but are quite inapplicable to cane molasses, as the quantity of potash present is usually only about one-half per cent.

The problem of finding a remunerative outlet for vacuum-pan molasses is undoubtedly one of the most difficult ones which owners of large factories have to solve, and for them the distillery appears to offer the easiest solution.

CHAPTER X.

Fermentation.—Nature of Ferments.—Conversion of Cane Sugar into Alcohol.—Setting up Wash.—Yield of Alcohol.—Distillation.—Forms of Stills.

WHEN cane-juice is allowed to stand for some hours various changes take place. The sugar disappears and a certain quantity of alcohol is found in its place. This change is known as fermentation. This term, however, is not limited to the conversion of sugar into alcohol, but is extended to other changes of the most various kinds, *e.g.*, the conversion of alcohol into acetic acid, etc.

It is now a matter of common knowledge that all these changes—which we term fermentation, putrefaction, and decay—are due to the life and growth, in the changed substance, of various minute organisms, and that if steps be taken to kill those present in a given substance, and to prevent the access of others, even the most easily putrescible substances, such as meat, fish, soup, milk, fruit, and the like, may be kept without change indefinitely. We have commercial examples on an enormous scale of the truth of this, in the various canned foods of all descriptions now so abundantly used. These are, for the most part, prepared by closing the food-sub-

stance in the tin, leaving a small hole in the lid for the escape of air. The tin and its contents are now heated to the temperature of boiling water in order to kill the putrefactive germs which are present,—not merely to remove the air, as is sometimes supposed,—and while hot the small hole is closed by means of a drop of solder. Cane-juice treated in the same manner would remain unchanged for any length of time. Air free from germs will not cause any fermentative or putrefactive change.

If a drop of liquid in which sugar is undergoing change from sugar to alcohol be examined under a microscope, a great number of little bladder-like bodies will be seen floating about in it, the appearance when highly magnified being as in the figure. These are the germs of alcoholic fermentation, or the yeast-plants, as they are called. Each little plant consists of a single cell, and multiplies by budding. A projection forms on one side of the parent cell, and this gradually grows until it becomes a perfect cell like the parent. This is known as reproduction by gemmation or budding. The yeast-plant also multiplies by forming spores in its interior. The contents collect into masses which, on the rupture of the surrounding cell-wall, are set free and develop into new yeast-cells. This method of multiplying is less common than the former.

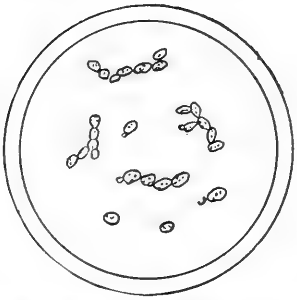

FIG. 19.—Yeast plant (highly magnified).

These cells are very minute, measuring on an average about $\frac{1}{4000}$ of an inch in diameter, so that the enormous number of 64,000,000,000 could go into the space of one cubic inch.

The change of sugar into alcohol is due to the life and growth of this particular organism. The sugar may be regarded as its food, and the alcohol as its waste product. Now, there are a great variety of these ferments, each of which produces certain definite changes. Thus we have the alcoholic ferment; the acetic ferment, which converts alcohol into acetic acid; the viscous ferment, which converts cane-juice into a thick, ropy fluid; the lactic ferment, which produces lactic acid; and many others. If any one of these be placed in a suitable medium it produces its own particular change. Hence, the alcoholic ferment always produces alcohol; the viscous ferment, the gummy matter which thickens the fluid and renders it ropy. The effect is just as certain and definite with the minute organisms as with larger ones, the resulting growths having the character of the organism sown: just as we get a maize crop if we sow maize, pigeon-peas if we plant pigeon-peas, and cane if we plant cane.

From this it follows that to get the best results it is necessary to exercise some care in the selection of the ferment when it is desired to convert sugar into alcohol for commercial purposes; for, if other ferments be sown into the fermenting liquid, other changes will go on at the expense of the sugar, less alcohol thus resulting.

Certain ferments require oxygen (air) for their

9

growth, hence their growth can be stopped by excluding air, or hastened by admitting it. The acetic ferment belongs to this latter class, and thus in the manufacture of vinegar it is necessary to have free access of air to the fermenting liquid. The alcoholic ferment belongs to the former class, and thus can live and grow in vessels from which air is excluded.

In the case of alcoholic fermentation of cane sugar the changes take place in two stages: 1. The sugar is rapidly converted into glucose or inverted. This change is effected by a soluble ferment, "invertase," secreted by the yeast-plant, the change only taking place if the solution is slightly acid, and is at once arrested if the solution is alkaline. This point is one well worth remembering by sugar-makers, as by tempering their juice as quickly as possible, and by keeping any juice which cannot be boiled at once slightly alkaline to the phenol-phthalein test, this inversion can be largely prevented. It is this inversion, of course, which prevents "sour" cane-juice yielding sugar when boiled, although it may have a high density when tested by the hydrometer before boiling. 2. The glucose thus produced is acted on by the yeast-plant, and converted into alcohol and carbonic-acid gas according to the following equation:

Under the action of invertase,

$$C_{12}H_{22}O_{11} \quad + \quad H_2O \quad = \quad 2C_6H_{12}O^6,$$

cane-sugar and water become glucose.

Under the action of the yeast-plant,

$$C_6H_{12}O_6 \quad = \quad 2CO_2 \quad + \quad 2C_2H_6O,$$

glucose becomes carbonic-acid gas and alcohol.

The presence of a large amount of alcohol arrests the development of the yeast-plant. Hence in the presence of a considerable amount of sugar the fermentation comes to an end before all the sugar is converted into alcohol; it is therefore wasteful to employ solutions which are too concentrated, as this results in loss of sugar.

When filter-presses are used in the manufacture of sugar there is no waste product to be converted into rum (the name given to the spirit produced from sugar-cane products) save molasses. This is mixed with water in such proportion that the resulting "wash" has a density of about 8° B. The wash is set up to ferment in vats of various sizes, depending on the size of the distillery, 1,000 gallons being a convenient size. Fermentation, as a rule, soon sets in without the addition of any ferment. Bubbles of carbonic-acid gas rise briskly to the surface, the liquid becomes slightly heated, and the density rapidly diminishes, falling to about 1° to 2° B. when the process is completed. This process usually occupies three or four days. This time could doubtless be shortened by adding to the fresh wash a small quantity of yeast or ferment taken from vats in which fermentation was active. It has been already stated that it is necessary that the solution be slightly acid in order that the cane sugar may be converted into glucose. It is usual, therefore, to add a small quantity of sulphuric acid to the wash to obtain this necessary condition. It is only necessary to add so much acid as will render the wash very slightly acid to litmus-paper, indicated by turning blue litmus-

paper slightly red. All waste products containing sugar, such as washings of various appliances, skimmings, etc., should be sent to the distillery to be utilised in setting up wash.

A great deal has been said, though but little definite seems to be known, about the production of a fine aroma and flavour in rum. This is no doubt due to the formation of various ethers and compound ethers during the process of fermentation. Good results in this direction appear to follow from setting up the wash at a higher density than 8° B., say from 10° to 13° B., allowing the fermentation to proceed slowly until all fermentation ceases, after which the wash is kept for twenty-four hours before distillation. Probably working in this way secondary fermentations set in, as the action of the alcoholic ferment becomes feeble. The subject is one which has been but little studied, and would repay further investigation. There are, of course, two courses open to the distiller: one, to produce rum when flavour and aroma must be obtained even at some expense of sugar, time, and trouble; the other, to make rectified spirit when quantity and freedom from aroma and flavour will be the objects aimed at.

When a solution of cane sugar is fermented under the most favourable conditions, 100 pounds of cane sugar yield 51.11 pounds of pure alcohol, or, in other words, slightly over 100 pounds of proof spirit, or 10.9 gallons; this is the theoretical yield, which is never reached in actual practice. With good appliances and careful working it ought to be possible to obtain from eighty to eighty-five per cent. of the

theoretical yield, or every 100 pounds of sugar in the wash ought to yield from eight and three-quarters to nine and a quarter gallons of proof-spirit.

When the fermentation of the wash has ceased, the alcohol is recovered by distillation, an operation depending on the fact that alcohol boils at a lower temperature than water, so that, when a mixture of water and alcohol is boiled, the vapour which first escapes consists very largely of alcohol, the vapour containing more and more water as the boiling continues, until at last it consists of little else than water. The simplest form of still in which the operation of distilling is conducted consists merely of a vessel in which the wash is boiled, provided with a long tube, usually coiled into a spiral form for convenience, into which the vapour passes and in which it is cooled as rapidly as possible; this cooling is effected by placing the coiled tube in water.

The only improvement commonly employed in this class of still consists in introducing one or two vessels or retorts between the body of the still and the condenser or worm. The use of these is to intercept the heavier vapours, thus rendering the rectification more perfect at one operation than it would be if the whole of the vapour passed direct to the condenser worm and so into the receiver.

Alcohol having a density of .864, or 40 over-proof,*

* The term proof-spirit is derived from the curious method of testing in use many years ago. A little of the spirit to be tested was poured upon a small heap of gunpowder, and the spirit ignited. If, when all the spirit had burned away, the gunpowder also took fire, the spirit was said to be "above proof;" if, on

is the usual strength of commercial rum. Spirit of a density from .864 to .900, or from 40 to 50 over-proof, is termed high wines, while weak spirit, from .900 to .967, or from 15 over-proof to 50 under-proof, is termed low wines, and from both of these spirit of full strength is recovered by redistillation. This redistillation is often economically effected by placing a quantity of low wines in the first retort and high wines in the second, the heat of the vapour from the wash in the still driving the alcohol, in a high state of concentration, into the condensing-worm.

In large distilleries what are known as continuous stills are employed. There are a great many modifications of this kind of apparatus; the principles underlying their construction and method of working will be understood from Fig. 20 and the following brief description.

The chief parts of the apparatus are: A, the wash-tank; B, condenser; C, the rectifying-column; D, the condensing-worm.

The wash flows, in the direction indicated by the arrows, from the wash-tank into the condenser, where it serves to cool the vapour which passes from the rectifying-column into the worm of the condenser; from the condenser the wash, now partially heated, flows by means of a pipe into the rectifying-column. This contains a number of horizontal plates or discs, perforated, yet so arranged

the other hand, the quantity of water in the spirit was so great as to render the gunpowder too wet to burn, the spirit was said to be "under-proof."

as to retain a thin film of moisture on the surface of each disc; the wash in its downward course over

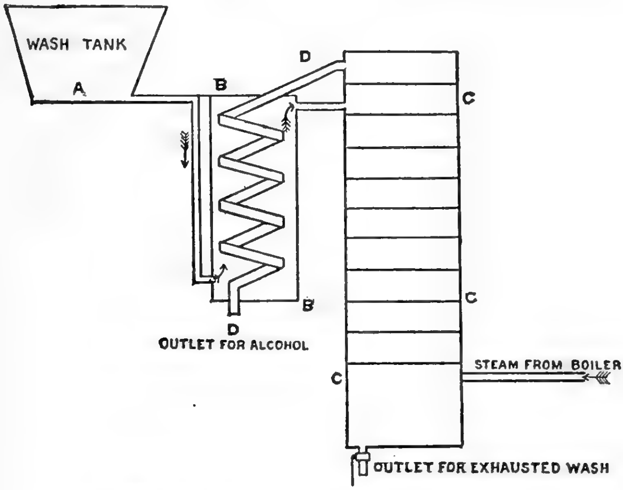

FIG. 20.—Diagram of continuous still.

the perforated discs meets the ascending hot vapours generated by means of steam admitted from a steam-boiler not shown in the figure. The more volatile portion of the wash—the alcohol—escapes through the pipe into the worm of the condenser, where it is condensed as already described. The less volatile portion passes downward into the chamber at the bottom of the rectifying-column, whence it is run off as it accumulates.

The exhausted residue from which the spirit has been distilled is known as dunder. It contains various mineral matters, as potash, phosphoric acid, etc., together with any sugar which has escaped fermentation. A certain quantity of it is usually employed, instead of water, in setting up fresh wash for fermentation, the unfermented sugar being thus saved,

while the mineral matter serves to supply plant-food, which is quite as necessary to the yeast-plant as to any other vegetable organism.

The value of rum depends largely on its flavour and aroma, and as the substances conferring the distinctive character are very volatile they are found in greatest quantity in the first runnings from the still; hence stills of the old or discontinuous type are often preferred, as by this means the first half of the returns, or any desired portion, can be kept separate in order to produce a spirit of first quality. From the continuous stills the spirit flows in a stream of almost unvarying quality, and in this case it is impossible to separate the product into portions differing in flavour and aroma.

Rum is usually coloured by means of burnt sugar. The colouring matter is prepared by heating muscovado sugar in an iron pan until it is converted into caramel, having a fine black colour. When sufficiently heated the fire is withdrawn, and strong proof rum is added, the whole being briskly stirred meanwhile. This solution is added to rum in such quantity as to produce the desired colour.

TABLE SHOWING TEMPERATURE OF STEAM AT PRESSURES FROM 0 TO 120 POUNDS PER SQUARE INCH.

Temperature, Fahrenheit.	Steam pressure, pounds per square inch.	Temperature, Centigrade.	Temperature, Fahrenheit.	Steam pressure, pounds per square inch.	Temperature, Centigrade.
Degrees.			Degrees.		
212	Water boils	100	270	27.30	132.2
215	.90	101.7	280	34.70	137.7
220	2.50	104.4	290	43.11	143.3
225	4.23	107.2	300	52.62	148.8
230	6.11	110.0	310	63.12	154.4
235	8.13	112.8	320	75.41	159.9
240	10.32	115.5	330	88.90	165.5
245	12.62	119 4	340	103.94	171.1
250	15.20	121.1	350	120.64	176.6
260	20.83	126.6			

LIST OF ELEMENTS WITH THEIR SYMBOLS AND COMBINING WEIGHTS.

Aluminium	Al.	27.3	Molybdenum	Mo.	96.0
Antimony	Sb.	122.3	Nickel	Ni.	58.7
Arsenic	As.	75.2	Niobium	Nb.	94.0
Barium	Ba.	137.2	Nitrogen	N.	14.0
Bismuth	Bi.	210.0	Osmium	Os.	199.1
Boron	B.	11.0	Oxygen	O.	16.0
Bromine	Br.	80.0	Palladium	Pd.	106.6
Cadmium	Cd.	112.0	Phosphorus	P.	31.0
Cæsium	Cs.	133.0	Platinum	Pt.	197.2
Calcium	Ca.	40.0	Potassium	K.	39.1
Carbon	C.	12.0	Rhodium	Rh.	104.2
Cerium	Ce.	92.2	Rubidium	Rb.	85.4
Chlorine	Cl.	35.5	Ruthenium	Ru.	104.4
Chromium	Cr.	52.1	Selenium	Se.	79.5
Cobalt	Co.	58.7	Silicon	Si.	28.1
Copper	Cu.	63.1	Silver	Ag.	107.9
Didymium	D.	95.0	Sodium	Na.	23.0
Erbium	E.	112.6	Strontium	Sr.	87.5
Fluorine	F.	19.0	Sulphur	S.	32.0
Glucinum	Gl.	9.3	Tantalum	Ta.	182.3
Gold	Au.	196.7	Tellurium	Te.	128.0
Hydrogen	H.	1.0	Thallium	Tl.	203.5
Indium	In.	113.4	Thorium	Th.	115.7
Iodine	I.	126.9	Tin	Sn.	118.1
Iridium	Ir.	196.9	Titanium	Ti.	50.0
Iron	Fe.	56.0	Tungsten	W.	184.0
Lanthanum	La.	92.9	Uranium	U.	237.6
Lead	Pb.	206.9	Vanadium	V.	51.3
Lithium	Li.	7.0	Yttrium	Y.	61.7
Magnesium	Mg.	24.0	Zinc	Zn.	65.2
Manganese	Mn.	54.0	Zirconium	Zr.	89.6
Mercury	Hg.	200.0			

TABLE OF DENSITIES, ETC., OF SACCHARINE SOLUTIONS.

Degrees, Beaumé.	Sugar, per cent.	Specific gravity.	In one gallon.		Degrees, Beaumé.	Sugar, per cent.	Specific gravity.	In one gallon.	
			Pounds sugar.	Pounds water.				Pounds sugar.	Pounds water.
0.0	0.00	1.0000	0.0000	10.0000	13.0	23.52	1.0992	2.5853	8.4067
0.5	0.90	1.0035	0.0903	9.9447	13.5	24.43	1.1034	2.6956	8.3384
1.0	1.80	1.0070	0.1812	9.8888	14.0	25.35	1.1077	2.8080	8.2690
1.5	2.69	1.0105	0.2718	9.8332	14.5	26.27	1.1120	2.9212	8.1988
2.0	3.59	1.0141	0.3640	9.7770	15.0	27.19	1.1163	3.0342	8.1288
2.5	4.49	1.0177	0.4569	9.7201	15.5	28.10	1.1206	3.1488	8.0572
3.0	5.39	1.0213	0.5504	9.6626	16.0	29.03	1.1250	3.2658	7.9842
3.5	6.29	1.0249	0.6446	9.6044	16.5	29.95	1.1294	3.3835	7.9105
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12.0	21.69	1.0909	2.3661	8.5429	25.0	45.83	1.2101	5.5458	6.5552
12.5	22.60	1.0951	2.4749	8.4761	25.5	46.78	1.2152	5.6847	6.4673

TABLE OF DENSITIES, ETC.—*Continued.*

Degrees, Beaumé.	Sugar, per cent.	Specific gravity.	In one gallon.		Degrees, Beaumé.	Sugar, per cent.	Specific gravity.	In one gallon.	
			Pounds sugar.	Pounds water.				Pounds sugar.	Pounds water.
26.0	47.73	1.2203	5.8244	6.3786	39.0	73.23	1.3714	10.0427	3.6713
26.5	48.68	1.2255	5.9657	6.2893	39.5	74.25	1.3780	10.2216	3.5584
27.0	49.63	1.2308	6.1084	6.1996	40.0	75.27	1.3846	10.4218	3.4242
27.5	50.59	1.2361	6.2534	6.1076	40.5	76.29	1.3913	10.6142	3.2988
28.0	51.55	1.2414	6.3994	6.0146	41.0	77.32	1.3981	10.8101	3.1709
23.5	52.51	1.2468	6.5469	5.9211	41.5	78.35	1.4049	11.0073	3.0417
29.0	53.47	1.2522	6.6955	5.8265	42.0	79.39	1.4118	11.2082	2.9098
29.5	54.44	1.2576	6.8463	5.7297	42.5	80.43	1.4187	11.4106	2.7764
30.0	55.47	1.2632	7.0069	5.6251	43.0	81.47	1.4267	11.6233	2.6437
30.5	56.37	1.2687	7.1516	5.5354	43.5	82.51	1.4328	11.8220	2.5060
31.0	57.34	1.2743	7.3068	5.4362	44.0	83.56	1.4400	12.0326	2,3674
31.5	58.32	1.2800	7.4649	5.3351	44.5	84.62	1.4472	12.2462	2.2258
32.0	59.29	1.2857	7.6229	5.2341	45.0	85.68	1.4545	12.4621	2.0829
32.5	60.27	1.2915	7.7838	5.1312	45.5	86.74	1.4619	12.6805	1.9385
33.0	61.25	1.2973	7.9459	5.0271	46.0	87.81	1.4694	12.9028	1.7912
33.5	62.23	1.3032	8.1098	4.9222	46.5	88.88	1.4769	13.1266	1.6424
34.0	63.22	1.3091	8.2761	4.8149	47.0	89.96	1.4845	13.3325	1.5125
34.5	64.21	1.3151	8.4442	4.7068	47.5	91.03	1.4922	13.5834	1.3386
35.0	65.20	1.3211	8.6135	4.5975	48.0	92.12	1.5000	13.8180	1.1820
35.5	66.19	1.3272	8.7847	4.4873	48.5	93.21	1.5079	14.0551	1.0239
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36.5	68.19	1.3395	9.1340	4.2610	49.5	95.40	1.5238	14.5370	0.7010
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